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During the final year of the award we devoted considerable time to an evaluation of the Institute's activities during its first years of operation. A great deal has been accomplished, as described in this report and the annual reports that preceded it. It was recognized in our final evaluation of the Institutes accomplishments, however, that the central theme of "human capabilities" to too broad to accurately represent the range of research conducted by our associated investigators. There is a need to identify more precisely the specific practical area or areas of science to which our research is applicable. Partly as a result of consultation with one of our visiting scientist, Dr Gilbert Ricard from Grumman Aircraft Corporation, we have elected to limit the Institute's future research focus to the subject of Human-Computer Interaction (HCI).

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Final Technical Report

Summary Descriptions of Research
for the period June 1, 1990
through May 31, 1994

Institute for the Study of Human Capabilities

URI - AFOSR #90-0215

Poplars Research and Conference Center
Indiana University
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Annual Technical Report

Summary

This Final Technical Report of the URI/AFOSR-supported Institute for the Study of Human Capabilities, at Indiana University, describes work done from June 1, 1990 through May 31, 1994. The Institute currently consists of thirteen affiliated laboratories, in which research is conducted by eighteen faculty investigators and a considerably larger number of graduate research assistants, technicians, programmers, and other staff members. One of the primary goals of the Institute have been to provide enhanced opportunities for interactions among these investigators, whose appointments are in six departments (Psychology, Speech and Hearing Sciences, Visual Science, Linguistics, Mathematics, Medical Science) and three schools or colleges of the University (College of Arts and Sciences, School of Optometry, School of Medicine). A second goal has been to familiarize scientists who conduct basic research on cognition, sensory processing, and decision making, with current problems in the field of human factors, or human engineering. The Institute has also served as a source of technical and scientific advice for researchers in government or industry who were working in areas represented in its laboratories.

We have continued, during this period, to make significant progress toward the long-term goals of the Institute. The Institute maintains an inter-laboratory, work-station based computer network, using the UNIX operating system. This network has been in operation for the past six years and is now in regular use for the exchange of information and, in several laboratories, for data analysis, graphics, and modeling. Other ways that the Institute-affiliated faculty interact have been by attending Institute-sponsored seminars presented by visiting scientists, through other interactions with these visitors, and through collaborative research. Funds made available through the Institute have been used to maintain, repair, and in some cases upgrade research apparatus in the affiliated laboratories. The Institute employed, or paid partial salaries of, several part-time technicians, programmers, and graduate student research assistants who conducted research under the direction of the faculty investigators. One half-time computer systems administrator maintained the inter-laboratory computer network.

During the final year of the award we devoted considerable time to an evaluation of the Institute's activities during its first six years of operation. A great deal has been accomplished, as described in this report and the annual reports that preceded it. It was recognized in our final evaluation of the Institutes accomplishments, however, that the central theme of "human capabilities" is too broad to accurately represent the range of research conducted by our associated investigators. There is a need to identify more precisely the specific practical area or areas of science to which our research is applicable. Partly as a result of consultation with one of our visiting scientists, Dr. Gilbert Ricard from Grumman Aircraft Corporation, we have elected to limit the Institute's future research focus to the subject of Human-Computer Interaction (HCI).

This change may eventually be reflected in a new name for the Institute, as well as some shift in its group of associated investigators. Among the new areas of research emphasis will be computer visualization, voice-control of computer systems, and human-capability-based limits on HCI. Obviously, much of our previous research emphasis on cognition and decision-making, sensory processing, and perceptual automaticity are directly relevant to HCI. Indiana University has three well-established programs that will have stronger ties with the reorganized Institute, the Department of

Computer Sciences, the Instructional Systems Technology Program, and the Center for Innovative Computer Applications. Because of this reorganization, we decided not to hold a fourth conference on Human Error, but instead to devote the final 18 months of this grant period to formulating plans for research and training relevant to the new emphasis on human-computer interaction. This effort has greatly enhanced our progress toward the Institute's original goal of educating the science faculty of a major research university about an important area of application,of their basic research, and encouraging them to broaden their research interests to include some applied projects.

One of the policies of the Institute has been to appoint Visiting Investigators in Human Factors to augment our basic-science oriented research staff. Visitors during this grant period have included Dr. Dan Fisk, a prominent human factors expert from Georgia Tech, Dr. Don Fisher from the University of Massachusetts, a specialist in mathematical models of human performance, and Dr. Andrew Dillon from Loughborough University in England, a specialist in human-computer interaction.

During six weeks in the spring semester of 1993 (mid-April through May), Dr. Gilbert Ricard from Grumman Aircraft served in this capacity. Dr. Ricard devoted most of his time to an assessment of national needs in the field of human factors, and of the particular range of research strengths at Indiana University. The decision to redirect the efforts of the Institute toward an HCI-related research, teaching, and consulting program at Indiana University was in part an outcome of Ricards work. A brief summary of his review paper is included.

The Institute, by these means, has provided partial support of research leading to the publication, during the three years, of 296 journal articles and book chapters, and the presentation of 169 papers at meetings of scientific societies.

Personnel

Investigators

Charles S. Watson, Ph.D., Director	Professor, Speech & Hearing Sciences Professor (part-time), Psychology
Richard M. Shiffrin, Ph.D., Associate Director	Waterman Professor, Psychology and Cognitive Science
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S. Lee Guth, Ph.D.	Professor, Psychology and Visual Sciences
David B. Pisoni, Ph.D.	Professor, Psychology and Cognitive Science
Robert Port, Ph.D.	Associate Professor, Linguistics, Computer Science, and Cognitive Science
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Larry N. Thibos, Ph.D.	Associate Professor, Visual Sciences
James T. Townsend, Ph.D.	Rudy Professor, Psychology and Cognitive Science

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Geoffrey P. Bingham, Ph.D.	Assistant Professor, Psychology and Cognitive Science
N. John Castellan, Jr., Ph.D.	Professor, Psychology and Cognitive Science
Michael Gasser, Ph.D.	Assistant Professor, Computer Science and Department of Linguistics
Diane Kewley-Port, Ph.D.	Associate Professor, Speech &Hearing Sciences
Gary R. Kidd, Ph.D.	Associate Scientist, Speech & Hearing Sciences
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Ted Bell, 1990	University of California at Los Angeles
Dan Fisk, 1991	Georgia Tech
Don Fisher, 1991	University of Massachusetts
Andrew Dillon, 1992	HUSAT, Loughborough Univ., U.K.
Gilbert Ricard, 1993	Grumman Aircraft Corp.

The following personnel contributed to research projects described in this report. Those entirely or partially supported by the Institute are identified by asterisks.

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Martha Rinker	B.S.	Tactile Perception
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Roger P. Rhodes	B.S.	Tactile Perception

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Carol Rhodes	B.A.	Institute for the Study of Human Capabilities

Introduction

This Final Technical Report of AFOSR grant #90-0215, which has provided major support for the Institute for the Study of Human Capabilities at Indiana University, describes work in several areas, all of which are concerned with problems of skilled human performance. The Institute's investigators are primarily active in the fields of human cognition and decision making, and in sensory processes including vision, audition (including speech perception), and touch; research in those areas represent the major content of this report.

Specific projects continue to focus on human subjects' abilities to use information obtained from visual, auditory, and tactile displays. Both empirical and theoretical studies continue to be conducted. Studies of human cognition include a new theory of the limits of human auditory signal detection, the discovery of a common source of variance in auditory and visual speech perception (lipreading), automatization of perceptual processes, and automatization as a mechanism for overcoming attentional limitations.

Research Support. The research projects described in this report have been supported either partially or completely by the URI/AFOSR grant to the Institute for the Study of Human Capabilities. It is emphasized, however, that the majority of the investigators also receive project support from other agencies, as listed on pages 78 through 80 of this report. Institute funding, while a small portion of the total research support of the 13 affiliated laboratories, is a primary reason for the interdisciplinary cooperation that has developed among its affiliated scientists, during the past seven years. Institute funds have been used, roughly in order of amounts expended to:

(a) support graduate-student research assistants working on Institute-proposed projects;

(b) provide supplementary technical assistance for equipment design, maintenance, and computer program development;

(c) maintain and enhance apparatus for research in auditory signal detection;

(d) support short- and long-term visits to the Institute by scientists interested in application of basic research to human engineering problems; this category includes the support of three national conferences on Human Error, held on the IU campus in 1990, 1991, and 1992.

(e) support a one-half time secretary-administrator, and one-third summer salary for the Institute Director;

(f) support travel to scientific meetings for the purpose of reporting Institute-supported research.

Areas of Research. Current research projects in Institute-affiliated laboratories include studies in the following categories:

I. Auditory Discrimination: the psychophysics of auditory capabilities, the limits of auditory attentional capacity as revealed in the perception of tonal patterns; the ability

to discriminate signals composed of gaussian noise samples.

II. Multi-Modality Testing: comparison of individual differences in speech processing by ear and by eye.

III. Tactile Discrimination: development of tactile arrays, and studies of interference in tactile localization.

IV. Visual Discrimination: human peripheral vision, human visual optics, spatial processing of color information, perception of moving objects, and color theory.

V. Cognition and Decision Making: multi-stage decision making, perception of multidimensional complex sounds,differences between visual and memory search, connectionist models for auditory and speech perception, use of fault trees, and computer-based instruction.

VI. Connectionist Models of Sensory and Cognitive Processes: development and testing of neural networks for identification and discrimination of tonal sequences.

VII. New research in the Speech Research Laboratory: speech analysis, synthesis and perception, including word recognition and lexical access.

Form and Content of the Reports. It is not our intention to provide sufficient information in the brief project descriptions included here so that any of this work could be replicated. We believe such detail is best reserved for the descriptions of the work that will be submitted to appropriate journals, and specifically discourage any citation of reports which, like these, have not been through the scrutiny of independent peer review. We do hope, however, that the early knowledge of research that is underway or that, because of publication lags, will not appear for some time in the open literature, may be of value to colleagues who are working in closely related areas. We encourage readers of these brief reports to write to individual investigators if further detail is desired on any of the projects. In some instances draft manuscripts or technical reports are available, and we will do our best to provide whatever information is requested.

Personnel Changes. Richard Shiffrin has served as Associate Director of the Institute during the last two years (replacing James Craig in that position) and his cooperation has been especially valuable because he also serves as Director of the Indiana University Cognitive Science Program. It seems clear that the applied field of human factors, if it is to move ahead with the rest of the scientific community, must adapt to (and benefit from) the "cognitive revolution."

One of the long-term goals of the Institute was to recruit a person in the field of human factors research to the Indiana University faculty. During the final year of AFOSR support, we were successful in hiring Dr. Andrew Dillon, who had served in 1991 as one of the long-term visitors supported by this AFOSR award. Dillon was formerly a senior scientist at the Institute for Human Sciences and Advanced Technology (HUSAT) Centre at Loughborough University, England. His training and research experience are in psychology, human factors, and human-computer interaction. Those areas of expertise are ideally suited to the Institute's new focus on research related to human-computer interaction, as discussed earlier. Dillon was appointed as an associate professor in the IU School of Library and Information Science, and as Assistant Director of the Institute. During his initial year at Indiana he has been active in organizing the educational component of the Institutes new

program in human-computer interaction.

Reprints. The bibliography at the end of this report lists articles by members of our research groups that have appeared over the past four years.

The design, conduct, and interpretation of experiments in these reports typically reflects the joint intellectual efforts of investigators, research assistants, and many others who participate in the research projects. While we try to give credit where it is due, the ownership of initial ideas is often impossible to establish. We are only certain of who does the work involved in the collection and analyses of data, and who writes the final papers; those persons are formally recognized through authorship, but often a "group as a whole" is as close as one can come to the source of the original ideas for an experiment or for forms of analysis or, most importantly, for a theory. It is a pleasure, at any rate, to work with colleagues who seem to have an inexhaustible reserve of new ways to think about interesting problems.

Dedication. This Final Technical Report is dedicated to the memory of Professor John Castellan, whose untimely death in December 21, 1993, represented a major loss to the Institute, Indiana University, and the national scholarly community. John had recently been elected president of the Federation of Behavioral Science Societies, a well-deserved recognition of his scholarly accomplishments and his contributions to of each of the many organizations of which he was a valued member. His whole-hearted support of the Institute was highly valued, his enthusiasm, wisdom, and good humor are sorely missed.

CSW

I. Auditory Discrimination

Recognition of synthetic speech by hearing-impaired elderly listeners.
Humes, Nelson, Pisoni

The Modified Rhyme Test (MRT), recorded using natural speech and two forms of synthetic speech, DECtalk and Votrax, was used to measure both open- set and closed-set speech- recognition performance. Performance of hearing-impaired elderly listeners was compared to two groups of young normal hearing adults, one listening in quiet and the other listening in a background of spectrally shaped noise designed to simulate the peripheral hearing loss of the elderly. The results revealed significant effects of both group and talker. Votrax synthetic speech yielded significant decrements in speech recognition compared to either natural or DECtalk synthetic speech for all three subject groups. There were no differences in performance between natural speech and DECtalk speech for the elderly hearing-impaired listeners or the young listeners with simulated hearing loss. The normal-hearing young adults listening in quiet out-performed both of the other groups, but there were no differences in performance between the young listeners with simulated hearing loss and the elderly hearing- impaired listeners. When the closed-set identification of synthetic speech was compared to its open-set recognition, the hearing-impaired elderly gained as much from the reduction in stimulus/response uncertainty as the two younger groups. Finally, among the elderly hearing-impaired listeners, speech-recognition performance was correlated negatively with hearing sensitivity, but scores were correlated positively among the different talker conditions. Those listeners with the greatest hearing loss had the most difficulty understanding speech and those having the most trouble understanding natural speech also had the greatest difficulty with synthetic speech.

Speech-identification difficulties of the hearing-impaired elderly: The contributions of auditory-processing deficits.
Humes, Christopherson

The present study examined the performance of four subject groups on several temporally based measures of auditory processing and several measures of speech identification. The four subject groups were: (a) young normal-hearing adults; (b) hearing-impaired elderly subjects ranging in age from 65-75 years; (c) hearing-impaired elderly adults ranging in age from 76-86 years; and (d) young normal-hearing listeners with hearing loss simulated with a spectrally shaped masking noise adjusted to match the actual hearing loss of the two elderly groups. In addition to between-group analyses of performance on the auditory-processing and speech-identification tasks, correlational and regression analyses within the two groups of elderly hearing- impaired listeners were performed. The results revealed that the threshold elevation accompanying sensorineural hearing loss was the primary factor affecting the speech-identification performance of the hearing-impaired elderly on both a group and an individual basis. However, significant increases in the proportion of speech-identification score variance accounted for were obtained in the elderly subjects by including various measures of auditory processing.

Modeling the effects of sensorineural hearing loss.
Humes, Jesteadt

We have been investigating a model of the effects of sensorineural hearing loss on auditory perception. The model makes use of the modified power-law with compressed intemal noise (Humes et al. #34; Humes and Jesteadt, #61) to describe the growth of loudness with sound intensity. This loudness- growth function has just one free parameter; the exponent of the power-law, P. Optimal values of P have been found to be in the range 0.1 to 0.3 for normal, noise-masked normal, and hearing-impaired listeners. The result is a compressive input-output function that is not unlike those described in auditory physiology. The more rapid growth of loudness (recruitment), observed in listeners with sensorineural hearing loss, is accommodated in the model by simply replacing the normal quiet threshold with the elevated quiet threshold of the impaired listeners. That is, no change in exponent, P, is required for the two groups of listeners.

To make the model more comprehensive, the modified power-law function is incorporated into the excitation-pattern model of Zwicker. The modified powerlaw model simply replaces Zwicker's equation for the transformation from excitation to specific loudness. Different rules, based on our work on the additivity of masking, are also used in this model to combine the excitation for individual components of complex multi-component signals. Essentially, it is demonstrated that the combined excitation of multi-component signals is more accurately determined if the combination takes place in the specific-loudness domain and is transformed back into excitation, rather than simply combining the excitation, as is typically done. This feature of the model results in a more accurate representation of the peripheral encoding of complex sounds, such as speech, in normal and sensorineural ears than obtained with previous excitation-pattern models.

Dimension-specific processing capacity for auditory patterns.
Watson, Kidd

Several recent studies of what we have called the "processing capacity" for complex auditory patterns have supported the conclusion that, when a novel stimulus is presented in a discrimination task, the ability to resolve pattem details on a given dimension is affected by the amount of variation on that dimension. When the amount of variation on a dimension is very low, pattern discrimination is determined by absolute physical values (thresholds). However, when the amount of variation is high, discrimination is determined by the proportion of the pattern that is changed (Watson and Kidd, 1987,1989). We have proposed that the discriminability of a change in any dimension of a complex sound is determined by the sound's current amount of variation on that dimension. This dimension-specific processing capacity hypothesis has been tested in an experiment that measured threshold values of f/f for changes in a single target tone in nine-tone patterns. The amount of variation per dimension was manipulated in the frequency and temporal dimensions. Variation on these dimensions was manipulated by including different numbers of frequencies and durations in the patterns. A pattem included three, six, or nine different frequencies and durations. The three levels of variation per dimension were factorially combined to produce nine pattern-variation conditions. Results have revealed a considerable decrement in frequency-discrimination performance with increases in the number of different frequencies, but little or no effect with increases in the number of different durations. Additional experiments in which rhythmic complexity (regular vs. irregular arrangements of durations) was manipulated, rather than the number of different durations, produced a similar pattern of results. Thus, at least under these conditions, listeners are only affected by changes

in the amount of variation in tonal patterns when that variation is on the same dimension as the change to be discriminated. We are continuing to test other combinations of dimensions and other target dimensions to determine the conditions under which this type of result will hold. Our previous research suggests that not all conditions will reveal this same insensitivity to variation on the irrelevant dimension.

The effect of position uncertainty on frequency discrimination with well-learned patterns.
Kidd, Watson, Drennan

Several earlier experiments have demonstrated large improvements in the discriminability of changes in a single "target" tone in a multi-tone sequence as pattern uncertainty (defined in terms of the number of different patterns used in an experiment) is reduced. A new experiment has been conducted to test the effect of variation in position uncertainty (i.e., uncertainty with respect to the serial position of a target tone) when the same pattern is presented on every trial. The goal was to determine the degree to which knowledge of the serial position of the target tone can facilitate discrimination of target-tone changes in well-learned sequences. Frequency-discrimination thresholds were determined for each component of a single ten-tone pattern (using multiple adaptive tracks in a S/2AFC paradigm) after several days of training under position uncertainty. Following this training, discrimination thresholds for four of the components were tested under minimal uncertainty. The target position was held constant over trials for several testing sessions. The results showed only a slight improvement , indicating that position uncertainty is not a major factor in discrimination, once a pattern is well-learned.

The proportion-of-the-total-duration (PTD) rule holds for duration discrimination.
Gary R. Kidd, Charles S. Watson

In previous work, we demonstrated that frequency resolving power for each individual component of an unfamiliar sequence of tones increases with the component's proportion of the total sequence duration (Kidd & Watson, 1992). This work has now been extended to the case of duration discrimination. In this case, the dimension affected by changes in PTD (i.e., time) is also the primary dimension of variation within the patterns, as well as the dimension to which listeners must attend to perform the task. Listeners were asked to detect a change in the duration of a single tone in a five-tone pattern using a modified two-alternative forced choice procedure. Target-tone durations were determined by the PTD value (0.1, 0.2, or 0.4) and the total pattern duration (250 msec or 750 msec). Context-tone durations were determined randomly on each trial. A single frequency pattern, consisting of a sequence of ascending frequencies, was used throughout the experiment. The pattern of results obtained was essentially the same as that found in the frequency-discrimination experiments. Increases in the proportion of the total pattern duration occupied by the target tone consistently resulted in lower duration-discrimination thresholds.

Use of the psychophysical method of adjustment in tonal pattern discrimination.
Charles S. Watson, Gary R. Kidd, Aimee Surprenant, Ward R. Drennan

A difficulty in tonal-pattern research is that several thousand trials are typically required to approach asymptotic discrimination performance under minimal-uncertainty testing conditions. One

solution to this problem is to use the method of adjustment to determine thresholds, rather than a forced-choice psychophysical method. In this study the extremely brief times that are required for a listener to achieve perceptual isolation for single components of a multi-tone patterns using the method of adjustment instead of a forced-choice method (minutes as opposed to hours) are demonstrated. A quantitative criterion for "perceptual isolation" is reached when a frequency match is made that is as close to the standard as can be achieved when the standard and variable tones are both presented in isolation, rather than in pattern contexts. Not all adjustments are this accurate, however. The most useful distinction between difficult and easy adjustments is shown to be the percent of all the adjustments, for a given combination of target and context tones, that meet this perceptual-isolation criterion.

Properties of the structure of multi-tone sequential patterns that determine the difficulty of perceptually isolating single target components.
Charles S. Watson, Gary R. Kidd, Aimee Surprenant, Ward R. Drennan

A method of adjustment was used to establish the importance of each of several structural properties of the context tones, in nine-tone sequences, in determining the perceptual isolability of target components. Successful "perceptual isolation" of a target tone was assumed to be achieved when frequency matches were as accurate as those achieved for tones presented in isolation, generally meaning values of $\Delta f/f$ less than 1%--2% for the 50-ms tones in these sequences. The context property that was found to primarily affect the frequency matches was the separation, in Hz, between the target tone and both the local and (to a lesser degree) the remote context tones. Other than its bandwidth, the form of the local pitch contour (the target tone plus the single tones immediately before and after it) had no clear effect on the ability to "hear out" the target tone, i.e., whether the local context was ascending, descending, concave up, or concave down. The contours of the remote context tones (first and last three in the patterns) likewise had no effect on performance. Performance ranged from 25% target tones isolated for the most difficult conditions to 90% for the easiest.

Additivity of Auditory Masking
Humes, Cokely, Lee, Jesteadt & Halling

We continue to explore the additivity of masking in normal-hearing listeners. Issues investigated include the influence of spectral and/or temporal overlap of the maskers with each other or with the signal. Results to date indicate that the linear power-summation of masking is the exception rather than the rule and is restricted to the special case of temporal AND spectral overlap of both maskers.

Identification of Multidimensional Auditory Stimuli
Humes, Christopherson, Nosofsky

Experiments are being conducted on normal-hearing listeners' ability to identify artificial acoustic stimuli having stimulus characteristics that vary along three independent dimensions. In one experiment, stimuli had one of two values of temporal onset (abrupt/gradual), harmonicity of components (harmonic/inharmonic), and spectral envelope (smooth/peaked). Stimulus values along each dimension were simultaneously presented (parallel) in 100-ms tokens. Subjects identification

performance was consistent with their identification on the basis of one preferred stimulus dimension, with different subjects preferring different dimensions. With training, subjects could learn to focus their attention on previously nonpreferred dimensions. Extension of these initial results to stimuli with three new dimensions (spectral location of noise, duration of temporal gap, extent of frequency transition) presented sequentially (series) is being examined. Eventually, this work will be extended to hearing-impaired elderly listeners to examine their ability to learn to use new cues to identify complex multidimensional stimuli.

The effects of training method on frequency discrimination for individual components of complex tonal patterns.
Robert F. Port, Catherine L. Rogers, Charles S. Watson, Gary R. Kidd

It has been assumed that subjects trained to detect increments in the frequency of all components of complex tonal patterns (broad focus) would be less accurate in detecting changes in a single target tone than subjects who have been trained to detect changes in only that component [e.g., Watson et al., *J. Acoust. Soc. Am.* **60**, 1176--1186 (1976)]. In several experiments, using a number of 750-ms ten-tone patterns, subjects were trained using one of three methods: in the first two, a S/2AFC procedure was used to train subjects to detect frequency increments in a specific target tone (group one) or to detect frequency increments that could occur in any of the ten components (group two), and in the third, subjects were trained only to identify the individual patterns. Subjects trained using these methods were tested on their ability to detect changes in various components of the patterns, including the target tone for the first group. In all of these experiments, only very slight differences in performance were found among the different groups. These results suggest that lengthy experience with a given pattern allows a listener to discriminate small differences in frequency in any of the individual components of that pattern, relatively independent of the nature of that experience.

Selective attention to spectral-temporal regions of auditory patterns.
Charles S. Watson, Xiaofeng Li, Gary R. Kidd, Yijian Zheng.

Training to attend selectively to certain spectral-temporal components of four tonal patterns has been found to have only slight effects on discrimination performance [Port et al., J. Acoust. Soc. Am. 93, 2315(A) (1993)]. In a new version of this experiment, a novel pattern (ten 50-ms tones, 300 3 kHz in frequency) was presented on each trial. One group of listeners was trained to discriminate changes in the early low-frequency region of the patterns, a second group in the late high-frequency regions, and a control group was trained with changes occurring throughout the patterns. Training was conducted for ten sessions, followed by testing at all spectral-temporal positions. Effects of selective training were much more substantial than in the earlier four-pattern experiment. Under the high stimulus-uncertainty conditions, attentional training yields the predicted results: Discrimination is relatively improved for trained, compared to untrained regions. An unexpected result was that the control group's performance was significantly more accurate than that of earlier selective-attention group. It is possible that efforts to selectively attend to some spectral-temporal region of an unfamiliar pattern may reduce overall discrimination performance, compared to that achieved when listening for any change in the pattern.

Temporally directed attention in the detection and discrimination of auditory pattern components.
Gary R. Kidd

Thresholds for detection and frequency discrimination were determined for tones that occurred at unexpected temporal locations within twelve-tone sequences. Expectancies were established by repeated presentations of a standard pattern on each trial. Temporal deviations were introduced in comparison patterns by advancing or delaying the onset of a single "target" tone while maintaining the rhythmic structure of the surrounding context. Rhythmic patterns consisting of 350-ms and 150-ms intertone intervals were used to allow for a large range of temporal displacements. Thresholds were determined for target tones that were advanced ("early" targets) or delayed ("late" targets) by various degrees. Thresholds for displaced targets were elevated with respect to nondisplaced targets for both detection and discrimination. However, for most listeners, there was little or no effect of temporal displacement on detection except when targets were advanced by 200 ms or more.

The effect of temporal deviations was found to be considerably more robust for frequency discrimination than for detection. Testing in a variety of temporal contexts (including different numbers of tones, tempos, and rhythms) reveled a consistent effect of temporal displacement on frequency discrimination, even in rhythmic contexts in which little or no effect on detection was observed. The results are consistent with the view that, when presented with an auditory pattern, a listener's attention is dynamically allocated in time in response to the temporal structure of the pattern.

Publications

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Watson, C. S., Kidd, G. R., Surprenant, A., & Drennan, W. R. (1993). Use of the psychophysical method of adjustment in tonal pattern discrimination. J. Acoust. Soc. Am., 93, Pt. 2, 2315.

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Psychophysics of vowels

Effects of levels of stimulus uncertainty on discrimination of vowels
Kewley-Port

A series of experiments has examined the *discrimination of vowel formants* in a variety of phonetic contexts. In the first experiment, thresholds for F1 and F2 formant-frequency discrimination were obtained for ten synthetic, steady-state English vowels (Kewley-Port, 1990a; Kewley-Port and Watson, 1993). Thresholds were estimated, under minimal stimulus uncertainty, for both increments and decrements in either F1 and F2 formant frequencies. Reliable measurements of thresholds were obtained for most formants tested except when a harmonic of the fundamental fell at the center frequency of the formant. Excluding those cases, thresholds of ΔF as a function of formant frequency are best described as a piecewise-linear function which is constant at 14 Hz in the F1 frequency region (< 800 Hz), and increases linearly in the F2 region as shown in Fig. 1. In the F2 region, the resolution as $\Delta F/F$ is about 1.5%. The thresholds are similar to the most accurate formant discrimination previously reported in the F1 region, but about a factor of three lower in the F2 region.

Another series of minimal-uncertainty experiments obtained thresholds for one vowel, /I/, in a variety of consonantal contexts, /b, d, g, z, m, l/ (Kewley-Port & Watson, 1991). For F1 and F2, the resulting thresholds were a factor of 4-5 smaller than those reported in Mermelstein (1978) (who tested under medium levels of stimulus uncertainty). Relative to the isolated vowels, the thresholds for F1 did not generally change in consonantal context (although ΔF for /mIm/ and /lIl/ were larger by about 25%). Thresholds for F2 showed no significant change for /I/ in /bIb/, /dId/, and /zIz/, but for a few f\subjects, a two-to-three-fold increase in ΔF threshold was obtained for /gIg/, /mIm/, and /lIl/. Additional experiments have estimated formant-frequency discrimination thresholds under *medium levels of stimulus uncertainty* (Kewley-Port, 1992). While longer training was required to approach asymptote, final thresholds were generally similar to those obtained for isolated vowels. Apparently, auditory acuity for formant frequency discrimination in well-trained subjects is generally the same for vowels in isolation and in CVC contexts, under both minimal and medium levels of stimulus uncertainty. Although the result that listeners perform similarly across those experimental conditions is not unexpected, given the life-long experience of the listener with the perception of "natural" vowels, the discrimination capabilities of the auditory system for vowels much better than expected.

Effect of glottal source on formant frequency discrimination.
Kewley-Port

Differences in the glottal source during speech production can allow a listener to distinguish a variety of characteristics of the talker, including differences in gender and speaking style. Vowel identification, discrimination and naturalness may be affected by variation in glottal source, vocal tract resonances, and the resulting interaction between the two. Little is known about the size of the effects for a given choice of glottal or formant synthesis parameters, or how to optimize the parameters of one in the face of variability in the other.

We have conducted three studies to determine the extent of interaction of source and vocal-tract resonance in an effort to provide a more systematic investigation of these problems. The first is a pilot study reported in Kewley-Port and Watson (1994) who examined the effect of different fundamental frequencies (F0) on the thresholds of F. A larger study (Kewley-Port, D., Li, X.,

Zheng, Y. and Beardsley, 1994) has been completed using six American English vowelsbased on speech produced by a male phonetician. Thresholds for formant discrimination were measured for two formants and two fundamental frequencies (101 and 126 Hz). The overall pattern of discrimination results reported in Kewley-Port and Watson (1994) for female vowels was replicated with male vowels but with a modest improvement in discrimination performance for male vowels. These results suggest that there exists an interaction between fundamental frequency and formant resonance that can cause large changes in discrimination thresholds for some stimulus conditions.

Excitation-Pattern Modeling.
Kewley-Port

Excitation-pattern models were successfully employed to describe the 20-dB range of thresholds obtained in a vowel-detection task (Kewley-Port, 1991). Modeling the thresholds for formant frequency discrimination requires a different approach than that taken for detection thresholds. A small change in one formant frequency of a steady-state vowel can produce level changes in harmonic components throughout the vowel. Thus it is necessary to determine whether level changes in components spectrally remote from the altered formant affect discrimination performance. Sommers and Kewley-Port (1993) have completed a series of experiments to investigate which harmonics affect discrimination performance. Synthetic tokens of the vowels /U/ and /e/ were generated by digitally summing the first 24 harmonics of a 200-Hz fundamental. Thresholds were obtained when: (1) all harmonics varied; (2) harmonic level variations were restricted to a subset of components spectrally close to the altered formant; and (3) harmonics remote from the shifted formant were excluded from the stimulus. Results indicated that thresholds for conditions (1) and (2) did not differ until level variations were restricted to two components. Thresholds for condition (3) were not significantly different from those obtained for vowels with a full complement of harmonics.

One goal of the Sommers and Kewley-Port (1993) experiments was to provide sufficient data to determine how to model spectral difference with excitation patterns. Preliminary analyses indicated that discrimination can be modeled by calculating a Euclidean spectral distance metric between the excitation pattern for the standard stimulus and the stimulus that was just discriminable from that standard. Analysis of the Sommers and Kewley-Port (1993) threshold results indicated that a fixed minimum of spectral distance was required before a change in formant frequency could be discriminated. This analysis will now be extended to account for the detailed differences in thresholds observed for female (Kewley-Port & Watson, 1994) and male (Kewley-Port et al., 1994) vowels.

Manuscripts and Published Presentations

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Kewley-Port, D. (1992). Effects of levels of stimulus uncertainty and consonantal context on formant frequency discrimination. J. Acoust. Soc. Am., **91**, No. 4, Pt. 2, S2338, presented at the *123rd Meeting of the Acoustical Society of America*, Salt Lake City, Utah, May, 1992.

Sommers, M. and Kewley-Port, D. (1993). Modelling formant frequency discrimination. *J. Acoust. Soc. Am.*, **93**, No. 4, Pt. 2, S2422, presented at the 125rd Meeting of the Acoustical Society of America, Ottawa, Canada, May, 1993.

Surprenant, A. and Kewley-Port, D. (1994). The effect of discriminability on dimensional interacations of pitch with vowel and consonant identity. *J. Acoust. Soc. Am.*, **95**, No. 5, Pt. 2, 2975, presented at the 127th meeting of the Acoustical Society of America, Boston, Massachusettes, June, 1994.

Kewley-Port, D., Li, X., Zheng, Y. and Beardsley, A. (1994). Fundamental frequency effects on thresholds for vowel formant discrimination. *J. Acoust. Soc. Am.*, **95**, No. 5, Pt. 2, 2978, presented at the 127th meeting of the Acoustical Society of America, Boston, Massachusettes, June, 1994.

Discriminability of noise samples
Robinson, Rickert

Consider a two-interval same-different task in which listeners are asked to discriminate between trials on which a sample of noise is presented twice and trials on which two different samples are presented. Previous research has used this method to determine the effects of a wide range of stimulus conditions including temporal location of an uncorrelated segment, duration, bandwidth, correlation, and overall level [T. E. Hanna, *Percept. Psychophys*, **36**, 409-416 (1984); Fallon, S. M. and Robinson, D. E. *J. Acoust. Soc. Am.*, **78**, S46, 1985; Fallon, S. M. and Robinson, D. E. *J. Acoust. Soc. Am.*, **81**, S33, 1987; S. F. Fallon and D. E. Robinson, *J. Acoust. Soc. Am.*, **92**, 2630-2635 (1992)]. The data indicate that discriminability is best when changes occur at the end of the sample and that the ratio of the duration of the target segment to the total duration is independent of overall duration.

During the last year, we have concentrated on developing a mathematical model of the discriminability of complex auditory patterns. The model, which we reported at the Spring 1993 meeting of The Acoustical Society of America, is based on Jeffress' leaky integrator [L. A. Jeffress, *J. Acoust. Soc. Am.*, **44**, 187-203 (1968)]. In our model, the envelopes of the waveforms from the two intervals of the same-different task are extracted by a leaky integrator. Next, the envelopes are jittered in amplitude. Finally, the envelope from the second interval is subtracted from the envelope of the first interval. The RMS of the differenced envelopes becomes the predictor variable. The leaky integrator imposes a temporal weighting function,1 - Exp[-B t], such that the envelope of the noise waveform increases slowly after the onset of the integration process. The time constant of the integrator, B, and the variance of the amplitude jitter are the two free parameters of the model.

The model provides an excellent fit to the data reported by Fallon and Robinson. It provides quantitative predictions of the improvement in performance as the target (uncorrelated) noise segment is moved from the beginning to the end of the burst and predicts the constant ratio of the duration of the target segment to the total duration.

Presentation

Robinson, D. and Rickert, M., (1993). A Stimulus Oriented Model for Discrimination of Gaussian Noise Samples, Revisited (Again). *AFOSR Conference*,Wright-Patterson AFB, Dayton, OH

Multi-stage decision making
Sorkin, Robinson

This work began several years ago in collaboration with Professor Robert D. Sorkin. That research led to the development of two models of combined person-person or person-machine detection systems. The first model describes a system referred to as an alerted monitoring (AM) system. An AM system is one in which a first detector alerts a second one to the possibility of a signal on a channel which is also monitored by the second detector. The second detector then makes an observation of the channel and, with knowledge of the decision made by the first stage detector, makes the final decision. Examples of AM systems are found in many applied situations, e. g. medical diagnosis, nuclear power plant control rooms, flight decks of commercial and military aircraft, etc. The AM model was developed using techniques from the Theory of Signal Detectability (TSD). The model suggests that AM systems can result in improved performance compared to a single-stage system. [Sorkin, R. D. and Woods, D. D. Systems with Human Monitors: A Signal Detection Analysis. *Human Computer Interaction,* 1984, **1,** 49-75. Sorkin, R. D. and Robinson, D. E. "Alerted-Monitors: Human Operators Aided by Automated Detectors", *DOT/OST/P-34/85/021, U.S. Dept. of Transportation,* 1985.

The second model of two-stage decision making, an outgrowth of the first, involves a slightly different situation. In the AM system, the second stage (typically a human operator) only monitors a channel when alerted to by the first stage. Another situation is one in which the task of the human is to monitor a noisy channel on which information about a potentially dangerous condition may appear. An alarm system also monitors an independently noisy channel for information about the same threatening condition. Using basic concepts of statistical decision theory, the Contingent Criterion Model of such a person-machine system has been developed. According to the model, the human should establish two criteria for responding: one contingent on an alarm from the automated detector and one, on no-alarm. The model shows large gains in performance compared to either detector alone. [Robinson, D. E. and Sorkin, R. D. A Contingent Criterion Model of Computer Assisted Detection, In *Trends in Ergonomics / Human Factors*, vol. II, R. Eberts and C. G. Eberts (Eds.), North-Holland: Amsterdam, 75-82, 1985.]

In addition to continuing our work on decision theory-based models of combined person-machine detection systems, we have extended our research in this area to include recognition systems consisting of an autoclassifier and a human monitor. In these systems, a human operator monitors a noisy channel and attempts to detect and classify signals. The operator is aided by an automated device which also attempts to detect and classify the same signals on an uncorrelated noisy channel. Both the automated device and the operator are modeled as multi-channel detection-recognition devices. For each stage (autoclassifier and operator), it is assumed that if the observation in any one of m channels exceeds criterion, a response of "yes" is made. Then, the channel having the largest output is selected as the one containing the target. By combining the Contingent Criterion model described above with a model of simultaneous recognition and detection (Starr, S. J.,Metz, C. E., Lusted, L. B., and Goodenough, D. J., *Radiology*, **116,** 533-538, 1975), we have developed the Contingent Criterion Recognition (CCR) model. The model indicates that large gains in target identification may be achieved relative to either stage operating alone.

Robustness of psychophysical measures
Rickert, Robinson

Also in the last year we have completed the mathematical analysis of several well-known measures of psychophysical performance. In this work we were interested in the degree to which such measures as d', P(C), P(C)max, and A' are "robust" with respect to violations in their underlying assumptions. The basic approach was to investigate how each of these measures varies with changes in criterion placement for various pairs of assumed underlying density functions. The pairs of density functions investigated were normal-normal, exponential-exponential, Chi Square-Noncentral Chi Square, and Rayleigh-Rice.

Our findings indicate that measures which rely on the assumption of equal-variance, normal densities, such as d' and P(C)max, are quite robust, particularly if extreme values of the criterion are avoided, e.g. changes in the criterion have small effects except for very low or very high false alarm rates. The so-called non-parametric measure, A', is not robust, and, in fact, shows large changes in magnitude as the criterion is varied on any of the density pairs we investigated.

II. Multi-Modality Testing

Multi-sensory temporal resolution.
Bell, Watson

Three experiments compared within-modality with cross-modality temporal resolution. Previous experiments have shown departures from Weber's Law, particularly when cross-modal judgments are required, implicating differential contributions from peripheral and central processes.

These studies systematically vary stimulus duration at a constant criterion (d' of unity). The literature (especially Sinex, 1979) indicates that temporal resolution within modality is better than resolution involving multiple sensory modes. Smaller changes in duration are discriminable at fixed performance levels when in a single modality than when multiple modalities are employed. Further, as the duration approaches zero, auditory and tactile within-modality or auditory-tactile cross modality is better than either auditory-visual or visual-tactile comparisons. Only certain conditions lead to departures from Weber's Law, however, that $\Delta T/T$ is constant. These results imply possible categorical processes involving cross-modal resolution and show differences in the point of subjective simultaneity. The present experiment used an adaptive strategy converging on a d' of unity to select stimulus durations. This procedure determines the just noticeable difference in temporal duration at a constant criterion level.

It was necessary first to establish a criterion-free method to study cross-modal temporal resolution. An algorithm was developed that directly computed d' and related measures (b, maximum expected percentage, and actual percentage), and adaptively changed test parameters to converge on a specify value, unity in the present experiment. d' was calculated every 50 trials under minimal-uncertainty conditions. On each trial, the subject compared a fixed time interval (Ts) to a comparison interval (Tc) and responded "same" or "different". The comparison interval was equally likely to be identical to the standard interval or incremented by a constant value, that was adaptively changed to converge on d' of unity. After five reversals in direction, the adaptive algorithm was halted and new parameters for the initial ΔT and step size were assigned. The values of Ts were in the range of 60 240 msec, and the initial ΔT in step size were varied depending on the Ts. Subjects were well-trained on judgments of this type and had previously completed approximately 30 - 60 hours of testing.

The algorithm adapts quickly to the just resolvable difference for d' of unity. After 400-600 trials, performance was stable in a narrow range of ΔT. Linear regression lines predicting the ΔT from trial blocks were flat, indicating asymptotic performance. The values for ΔT for each Ts at d' of unity agree with values interpolated from pilot experiments comparing fixed intervals.

Experiment 1: Auditory, tactile and visual temporal resolution: Within- and cross-modality judgements.

Subjects were seven young adult participants recruited from Indiana University. All subjects had normal hearing thresholds and reported no deficits in vision. Subjects participated approximately 120 hours and were paid for their participation. Standard intervals were 40, 60,120, or 240 msec in duration. The comparison interval was equally likely to be the same or to increase by a fixed ΔT. The intervals were marked by either visual, tactile, or auditory signals. The vibrotactile stimulator delivers to the fingertip an array of vibrators capable of producing spatial patterns; typically, this

device is used to present alphanumeric characters. The tactile stimulus employed in this experiment, however, was an asterisk presented in the center of the array. Visual stimuli were presented on a rapid decay phosphorous screen, and consisted of a small asterisk presented to the center of the screen. The auditory stimulus was a 1,000 Hz-tone of 20-msec duration with 5-msec rise and fall times. The auditory tone pips were presented at 83dB,SPL.

All stimulus presentation and data collection were controlled by a PDP laboratory computer system, model 11/83 with a real-time 18MHz clock. This processor controlled a Krohn-Height 5500 Ar oscillator as well as a digitally controlled attenuator. An external noise generator was also used, and all three were routed into a signal conditioning package including a mixer, filter, another attenuator, and a tone shaper for ramping auditory stimuli. The llc83 processor also controlled high speed phosphor display (model HP 1340 A display and a telesensory systems opticon model RlC). Auditory stimuli were presented monaurally by earphone (model TDH9 earphones encased in MX-41 cushions). A stimulus response box was also connected directly to the processor.

Within-modality thresholds were generally smaller than cross- modality thresholds over the range of Ts used in this experiment. These results are consistent with previous literature. The ratio of $\Delta T:T$ is shown as the average across subjects in the conditions for all modality combinations. The 60-msec duration produced the highest ratios ranging from .1.6 and the Mtio, rather than remaining constant, decreased with increases in the time interval systematically for all conditions. According to Weber's Law, these results should be relatively flat; these data are monotonically descending. Also, the within modality judgments, auditory-auditory, tactile-tactile, and visual-visual are the flattest of the functions, which would be expected. So although all results deviate from Weber's Law, the within-modality judgments are relatively closer in agreement than are the between-modality judgments.

Experiment 2: Auditory-visual temporal discrimination with increased memory demands.

To estimate contributions stemming from memory processes or central processes, a second experiment examined the effect of increasing the interstimulus comparison time from the 600 msec used in the previous experiment to two seconds. Thus, after the warning light, the standard interval was given, then a 2-sec delay before the comparison interval was presented. Only auditory and visual modalities were employed for this experiment, and the same adaptive procedure converging on d' of unity was used to estimate the ΔT associated with that value.

Three subjects who previously participated in experiment one continued for this experiment, thus, they were very practiced at the task. The ΔT at d' of one were lowest for the within-modality conditions. The auditory-auditory and visual-visual thresholds were lower than the auditory-visual and visual-auditory thresholds. The auditory within-modality thresholds were the lowest of all, averaging approximately 10 msec. The visual thresholds were somewhat higher, at 123 msec on the average.

Experiment 3: Auditory-visual temporal resolution at short ISI intervals.

A third experiment was performed to examine the effect of a very small interstimulus interval. The thought was that the first marker for the comparison tone would interfere with the final marker of the standard tone. Thus, the 60 msec interstimulus interval was employed. The hypothesis was that the auditory conditions would particularly interfere with other auditory stimuli and auditory and visual would not interfere with each other since the 60 msec delay is within the backward recognition masking for sensory stimuli.

Subjects had previously completed Experiment 2, thus were well practiced. The results indicated that the within-modality thresholds for the auditory sense were higher than the others, but that the visual sense were not. These results are probably due to the ability to perceive the four markers as a single percept, a rhythmic pattern, as opposed to discrete markers.

Conclusion:

Cross-modality thresholds are not in accordance with Weber's law (that $\Delta T/T$ remains constant). Within-modality trials were relatively in agreement with psychophysical predictions and were more finely discriminable implicating automaticity and more peripheral processes. Results are robust with respect to the interstimulus interval between Ts and Tc up to 2 seconds or longer. The longer delay did not interfere with the within-modality conditions; this result implies that a central representation must be used even for within-modality comparisons since performance is unaffected by delay. Experiment three further shows that an ISI of 60 msec showed no auditory backward masking effects, thus further implicating a central representation for within-modality judgements as well. Departures from Weber's law may not be due to peripheral versus central markers, but rather to attentional demands and STM processing.

A manuscript describing these results is in preparation.

Semantic-phonetic interference in word recognition: A "Lexical Stroop Effect."
Bell, Hennessey, Byers

Two experiments were conducted to examine the phonetic and semantic processing of words, in particular, semantic-related interference on phonetic or lexical processing. A same/different paradigm was used to measure response times (RT) as a function of phonetic or semantic properties. The stimulus set varied with respect to the phonetic and semantic relationships between pairs of stimulus words, and phonetic and semantic judgements are required of subjects. These conditions allow for comparisons between phonetic, lexical, and semantic influences in word identification processes, and further describe the influence of automatic and controlled processes.

Experiment 1:

Forty homophonic word pairs and their corresponding synonyms formed the stimulus set. Two words were presented simultaneously and the subject was to respond "same" or "different" by pressing a key. There were four conditions varying by the arrangement of homophones and synonyms. One of the conditions (ID) used the same word twice, this condition serves as a baseline. There were three other conditions or Pair types: the two words were either homophones, synonyms, or synonyms of the homophone.

Experiment 2

A second experiment was designed with a list of unrelated words substituted for the synonym of homophone pairs used in Experiment 1. It was hypothesized that the new unrelated pairs would eliminate interference.

Conclusion:

These experiments have demonstrated a "Lexical" stroop interference effect. The automatic semantic processing of a word that means the same as a homophone of the other target word produces interference or response competitions that require additional time to resolve. The "sound-alike" word was automatically activated due to the spreading of the semantic activation. Distinct meanings lead to an ambiguous phonetic encoding, biasing a "same" response when a "different" response would be required. When the semantic component is removed from the distractor condition, the effect vanishes completely. These data imply the direct use of phonetic codes rather than lexical codes in making semantic relatedness judgements. If the representation were lexical or orthographic, there would be no confusion regarding the distinct meaning of words. Therefore, there appears to be a direct downward connection from semantic to phonetic encodings that bypass lexical stages. Further, these data suggest a Parallel Distributed Processing account of this Stroop-like interference effect, specifically requiring continuous automatic processes under attentional control.

Correlations between auditory and visual speech processing ability: evidence for an modality-independent source of variance.
Watson, Qiu, Chamberlain, Li

Two experiments were run to determine whether the individual differences in auditory speech processing are predictable from those in speechreading, using a total of 90 normal-hearing subjects. Tests included single words and sentences. The speech was recorded on a video disk by a male actor (Bernstein and Eberhardt, 1986), Johns Hopkins Lipreading Corpus. The auditory speech was presented with a white noise masker, at -7 dB Sp/N. The correlations between overall auditory and visual performance were 0.52 and 0.45, in the two studies, suggesting the existence of a modality-independent ability to perceive linguistic "wholes" on the basis of linguistic fragments. Subjects also identified printed sentences with 40-60% of the portions of the letters deleted. Performance on the "visual-fragments" test also correlated significantly with visual and auditory speech processing. The importance of these findings is that they represent one of the few cases in which some of the variance in auditory speech recognition (among subjects) can be associated with other systematic variables. More obvious candidates, including spectral and temporal auditory acuity measures, and general intelligence, have been notably poor predictors of individual differences in speech perception measures.

A manuscript describing this research is under review, *Journal of the Acoustical Society of America.*.

III. Tactile Discrimination

Tactile attention.
Evans, Craig, Rinker

Previous studies in the laboratory showed that subjects had difficulty attending to a particular location on the skin and ignoring stimuli presented to adjacent locations. Specifically, subjects were required to identify a stimulus, typically a pattern moving across a fingerpad in a particular direction, and to ignore a moving pattern presented to an adjacent fingerpad. Using a paradigm similar to that used in visual studies of attention (four stimuli signalling two responses), it was determined that the interfering effect of nontarget stimuli primarily results from the nontarget signalling a different response, rather than interference (masking) at some relatively early stage of processing.

Using this four stimuli, two response paradigm, we investigated the effect of distance on the amount of interference. With visual stimuli, it has been shown that within a small area around a target stimulus increasing the spatial separation between the target and nontargets has no effect on interference. Beyond about 1 degree of visual angle, though, increasing distance results in a decrease in interference. These results have led to a "spotlight" of attention for visual stimuli. To test the appropriateness of this model for the skin, we presented nontarget stimuli to fingerpads that were adjacent to (near) the target site or the fingerpads that were nonadjacent (far). The results showed an equally large response-competition effect independent of the distance between target and nontarget. The results indicated that the focus of attention extends nearly undiminished across the fingers of one hand.

With the same paradigm, we moved the nontarget stimuli to the opposite hand. Unlike the results obtained with a simpler paradigm, we found an interference effect even when the target and nontarget stimuli were presented to opposite hands; however, the effect was diminished relative to that seen with stimuli presented to the same hand. Also, the size of the bilateral interference effect remained the same whether the two hands were placed next to one another or 25 cm apart.

In an additional study, we investigated the effect of spatial orientation on this interference effect. Interference is only seen when the target and nontarget are moving in different directions. When the two stimuli are moving in the same direction, whether the subject responds with the target or with the nontarget, they will be correct. In all the previous studies the two tactile displays were placed horizontally side by side in front of the subject. In the new studies, the displays were rotated 90 degrees and placed back to back. The subject gripped the two displays between the index finger and thumb. This rotation of the two displays changes the relative motion across the displays. Suppose a pattern is presented to the left hand and moved from right to left on the thumb and a second pattern is moved from right to left on the index finger when the two displays are horizontal. When the displays are placed vertically, the direction would change such that the movement would be "up" on the thumb and "down" on the index finger. The question we asked was whether subjects would respond as though they perceived the "local" pattern of motion across the fingerpad or the "external" pattern of motion. Consistently subjects responded in the latter fashion as though they perceived a single object moving between the index finger and thumb.

In another study examined the temporal course of the interference effect. The interference effect has been observed with brief temporal separations between the target and nontarget. Specifically, when the nontarget preceded the target by 50 to 100 msec. Similar findings with visual stimuli have been interpreted to mean that the nontarget "primes" a conflicting response. Recently we have investigated in greater detail the temporal course of the effect and have found that with tactile stimuli there is greater interference when the nontarget follows the target by a brief interval. These measurements have been extended to include sites on the forearm as well. The findings suggest that interruption may play a bigger role in the processing of tactile stimuli than in the processing of visual stimuli.

Many similarities were noted between the results obtained when two stimuli were presented to separate sites (a selective attention paradigm) and when two stimuli were presented to the same location (temporal masking paradigm). Using the four stimuli, two response paradigm, we have examined interference when two stimuli are presented to separate locations and when the stimuli are presented to the same location. The pattern of results is similar and has led us to conclude that a major component of the interference seen when two patterns are presented to the same location is due to response competition rather than masking.

Manuscript

Rinker, M.A., and Craig, J.C. (1994) The effect of spatial orientation on the perception of moving tactile stimuli. *Perception & Psychophysics*, **56**, 356-362.

Tactile speech.
Weisenberger, Craig, Abbott

This study evaluated a tactile speech aid. Using a principal component analysis, speech information was presented on a two-dimensional array of vibrators brought in contact with the subject's skin. Reasonably good levels of performance on several speech tasks, including lipreading, indicated that principal component design is a promising alternative to tactile vocoders.

IV. Visual Discrimination

A. Human Vision

Spatial Vision
Ye, Bradley, Zhang, Thibos

According to standard geometrical optics, monocular visual direction for a defocused image is determined by the chief ray which locates the center of the resulting blur circle. Recent studies of chromostereopsis have indicated that photoreceptor optics, i.e., the Stiles-Crawford effect (SCE), also affects apparent visual direction of defocused images. Because photoreceptor directional sensitivity peaks near the normal pupil center, marginal rays are less effective stimuli. If the pupil is displaced with respect to the SCE peak, the effective image may be shifted with respect to the chief ray by the SCE. Using wave optical analysis of a simple water eye model with an apodized pupil to account for the SCE, we calculated that visual direction of defocused images is significantly shifted when the model views through a displaced aperture. We have experimentally measured the effect of the SCE on apparent visual directions by comparing perceived visual directions of defocused images when subjects view through a displaced aperture under photopic and scotopic conditions. As our model predicted, the visual direction under scotopic conditions (no SCE) was determined by the chief ray, but visual direction at photopic levels was significantly different by an amount predicted by the midpoint of zero-crossings in the defocused retinal image in the apodized model eye.

Psychophysical determination of the factors limiting human peripheral vision.
Thibos, Bradley, Wang, Anderson

Gratings beyond the Nyquist limit of the peripheral retina are visible as aliased percepts when presented in isolation. However, recent experiments using complex stimuli (edges, lines, letters) suggest that aliased supra-Nyquist components (f2) may not be visible in the presence of sub-Nyquist gratings (f1). The purpose of our study was to test this hypothesis. Using a three-alternative forced-choice paradigm, subjects were required to discriminate a 2.5 deg patch of compound grating (f1+f2; components oriented orthogonally) from a simple grating (f1 only). In a control condition, discrimination performance increased from chance level to 100% correct over the f2 contrast range 5% -20% and average threshold contrast (75% correct) for 4 subjects was 14.5%. In the test condition, discrimination performance dropped significantly at any particular value of f2 contrast. However, this performance loss could be recovered by increasing f2 contrast. Average threshold contrast for the f2 component increased to 21%, representing a 0.16 log-unit increase over the control condition. These results demonstrate that under the conditions or our experiments, aliased supra-Nyquist components are visible in the presence of high contrast, sub-Nyquist gratings. We conclude that the peripheral visual system is capable of using aliased frequency components of a complex stimulus for pattern discrimination.

Manuscript

Wang, Y., Anderson, R.S., Thibos, L.N., and Bradley, A. (1993) Aliased frequencies enable the discrimination of compound gratings in peripheral vision. *Invest. Ophthal. Vis. Sci.* 34

(suppl.), 777.

Wang, YZ, Thibos, LN, and Bradley, A , (1993), Masking effect of sub-Nyquist gratings on the detection of sub- and supra-Nyquist gratings inperipheral vision. *Annual Meeting of the Opt. Soc. Am.*

Wang, YZ, Thibos, LN, Anderson, R., Bradley, A., and Heggerty, K. (1993) Effect of sampling array irregularity on the perception of supra-Nyquist moving gratings. *Annual meeting of the Am. Academy of Optometry.*

Wang, Y.Z., Bradley, A., and Thibos, LN. (1994) Sub-nyquist gratings are masked by aliased supra-nyquist gratings in peripheral vision.*Ophthalmol Vis. Sci.*, vol **35** ARVO, p. 1954.

Studies of Monocular diplopia
Bradley, Rahman, Zhang, Ye,Thibos

With the advent of widely-used contact lens corrections for most types of ametropia, we now have an aging population of ametropes unaccustomed to wearing spectacles. The onset of presbyopia in this population has posed new challenges for the eye care community. The presbyope has the option of relinquishing their contact lenses and adopting the more traditional spectacle lens corrections for presbyopes. The design principle of a bifocal spectacle lens allows the entering ray bundle to pass through different portions of the lens each with a different optical power. One area of the lens corrects distance vision and one near vision. By adjusting his or her gaze, the patient is able to select the region, and hence the optical power, of choice. Such manipulation of effective optical correction by changing direction of gaze is not possible with a contact lens. In order to provide a "bifocal" correction with a contact lens, part of the ray bundle entering the eye is corrected for distance and part for near. That is, at all times, part of the ray bundle will be out of focus. These lenses simultaneously create two rather than one image (simultaneous vision bifocals). We are studying the impact of this monocular diplopia on visual performance.

Bradley, A (1993) Simultaneous Bifocal and Multifocal Vision: from theory to practice. *Optom. Vis. Sci. 70*, 437-438.

Winn, B., Bradley, A., McGraw, P., Strang, N., and Thibos, LN (1994) Chromostereopsis and monocular chromatic diplopia in complex visual stimuli. *Invest. Ophthalmol Vis. Sci.*, vol **35**, *ARVO*, p 2169.

Chromostereopsis.
Ye, Zhang, Bradley, Thibos

We have shown that, with small pupils, chromostereopsis can be accounted for completely by monocular transverse chromatic aberration induced by displacement of the pupils from the visual axes. However, this simple model, which predicts chromostereopsis by the disparity between the short and long wavelength chief rays, cannot explain our observation that chromostereopsis declines with increasing pupil size. Several hypotheses may be advanced to explain the loss of chromostereopsis

with large pupils. First, because of other monochromatic aberrations (e.g. coma) there may be less disparity in the retinal images with large pupils. Second, the neural image may be shifted with respect to the chief ray by the Stiles-Crawford Effect (SCE) such that the optical chief ray no longer determines apparent visual direction. Finally, chromostereopsis may decline with increasing pupil size because stereopsis is degraded with the reduced image quality that accompanies increased pupil size. The latter hypothesis was rejected by the result of a control experiment which showed that changes of monocular visual direction caused by pupil displacements also decline with pupil diameter. Using wave optical analysis of a simplified model eye, we found that the separation between long and short wavelength images caused by pupil displacement is virtually unaffected by spherical aberration and coma, but becomes significantly attenuated when a fixed SCE is included in the model. Experimentally, we tested this explanation by measuring chromostereopsis with large pupils photopically and scotopically. As our model predicted, chromostereopsis with large pupils increased under scotopic conditions where the SCE is almost absent. This result is precisely predicted by the visual direction of the brightest point in the defocused, SCE-weighted, retinal image. We conclude that, at photopic levels, the SCE reduces chromostereopsis for large pupils by altering the apparent visual direction of blurred images.

Manuscripts

Thibos, LN. and Bradley A (1993) New Methods for discriminating neural and optical losses of vision. *Optom. Vis. Sci. 70*, 279-287.

Color vision.
Bradley, Zhang, Thibos

Neurophysiological and psychophysical studies of human color vision have sought to selectively stimulate only one of three channels (Achromatic, R/G, B/Y). Isoluminant color modulation along the constant-R&G and constant-B axes isolate the B/Y and R/G systems respectively, while not modulating the Achromatic system. We have shown previously this technique is compromised because chromatic aberrations introduce luminance artifacts into the retinal images of isoluminant grating stimuli. Here we show that lateral chromatic aberration also introduces color artifacts. We modeled the effect of chromatic aberration created by displacing the pupil 0.75mm from the visual axis (3 arcmin between 632.8 nm and 441.6 nm). We examined the effect of this aberration on isoluminant grating stimuli that were modulated through the white point along either the constant-B or constant R&G axes. Such stimuli may be created by mixtures of three monochromatic primaries (632.8 nm, 514.5 nm, 441.6 nm). Because both types of grating require simultaneous modulation of all three primaries, differential phase shifts in the image create the following effects. First, as previously noted, luminance modulations are introduced. Second, the modulation along the desired color axis is attenuated. Third, and most significantly for the isolation technique, color modulations are no longer restricted to a single axis. For example, CE space, the color modulation of a 5 c/deg R/G grating changes from a straight line into a ellipsoid with the minor axis 20% as long as the major axis. We conclude that experiments which depend critically upon the functional isolation technique may be significantly contaminated by lateral chromatic aberration which can convert a single axis color modulation in object space into a retinal image that simultaneously modulates along all three axes (Luminance, constant-B, constant R&G).

Manuscripts

Winn, B., Bradley, A., Strang, NC, McGraw, P., and Thibos, LN. (1994) Reversals of the color depth illusions explained by ocular chromatic aberration. *Vision Res.* (submitted)

Additional Manuscripts

Wang, YZ, Thibos, LN, and Bradley A (1994) Undersampling produces non-veridical motion perception, but not necessarily motion reversals, in peripheral vision. *Vision Res.* (submitted)

B. Human Factors and Applied (Clinical) Research

Visual capabilities with night vision goggles.
Bradley, Wilkinson, Thibos, Horner

During 1990-1991, there has been a tremendous interest in the visual capabilities and limitations of current Night Vision Goggle (NVG) technology. The argument in favor of using NVGs is simple: they enhance night vision and therefore expand the range of possible nocturnal activities. The argument against the NVGs is that they do not provide normal daytime visual function and therefore there are many activities that cannot be performed as accurately or safely with the NVGs. Put succinctly, both arguments are weak because of a glaring paucity of data describing visual capabilities with NVG's. We have performed a detailed evaluation of NVG-aided visual capability with a broad battery of tests that included standard Snellen letter acuity, contrast sensitivity, static vernier acuity, dynamic vernier acuity (e.g. how well can a pilot align a cross-hair with a moving target, or a refueling hose) and depth perception. We compared aided (with NVG) and unaided vision from twilight, Full Moon, 1/2 Moon, 1/4 Moon, Starlight, to Cloudy Starlight. We detailed the gain in visual performance achieved relative to the naked eye over a wide range of light levels, and we specify the results in terms of the increased range of light levels over which a particular criterion performance can be obtained, and the increased performance level achieved at a specific light level.

Manuscript

Bradley, A, (1994) Evaluation of Visual Acuity with Gen III Night Vision Goggles. NASA Technical Memorandom 108792.

Applied spatial vision models
Bradley, Thibos

The ISHC has funded Dr. Thibos' and Dr. Bradley's research into the optical and retinal limits of visual function. During 1991, they were both invited to participate in a US Air Force sponsored symposium (Armstrong Laboratory Advisory Group Conference in San Antonio, TX.) on new theoretical and experimental models that could be developed into working models by the US Air Force. Subsequent to this very successful meeting, a new book is in press (Applied Spatial Vision Models, ed. Peli) in which Drs. Bradley and Thibos are contributing two large chapters on the optical

and neural changes that accompany "off-axis" vision. This book summarizes the meeting and provides a genuine application of our fundamental sensory research to the mission of the US Air Force, and it fits nicely into the USAFOSR goals.

Book Chapters

Bradley A and Thibos LN (1995) Modeling off-axis vision - I: the optical effects of decentering visual targets or the eye's entrance pupil, in Applied Spatial Vision models, edited by Peli E., *World Scientific Press.*

Thibos, LN and Bradley A (1995) Modeling off-axis vision - II: the effect of spatial filtering and sampling by retinal neurons, in Applied Spatial Vision models, edited by Peli E.*World Scientific Press.*

Entopic visualization of retinal vascular detail.
Bradley, Applegate

In order to reach the site of phototransduction in the human eye, light must first pass through a dense vascular network in the retina The vascular supply is essential to the functional integrity of the human retina, and it is symptomatic of and responsible for many types of retinal disease. We have examined the hypothesis that the neural retina supplied by this retinal vascular system can resolve details of the vascular pattern better than the physician with current technology for viewing the retina. Preliminary data from normals support this hypothesis. The value of this observation will be greatly enhanced if patients with retinal vessel abnormalities can detect and monitor their vascular disease.

Manuscripts

Zhang, H., Bradley, A., Thibos, L.N., Applegate R.A., and Elsner, A. (1994) Comparison of Entoptic, Fundus Photographic and Fluorescein Angiographic Methods for Viewing the Retinal Vasculature. *Optical Soc. Am. Technical Digest, vol 2 (Vision and its Applications).* pp 228-231.

Zhang, H., Bradley, A., and Applegate R.A. (1993) Comparison of entoptic and fundus camera images of the human retinal blood vessels. AAO, Boston.

Evaluation of clinical tests of contrast sensitivity.
Bradley

Contrast sensitivity has been examined experimentally for over 20 years, but it has only recently become available to the average clinician. Tests of contrast sensitivity are designed to be diagnostic for certain types of disease, but perhaps more important, they provide a more complete documentation of a patient's visual disability. Attempts have been made in the USAF and in several other professions employing visually demanding tasks to include contrast sensitivity as a test procedure by which to select or eliminate individuals. We are in the process of evaluating the sensitivity and reliability of clinical contrast sensitivity tests.

Manuscript

Thibos, LN, Still, D., and Bradley, A (1994) Characterization of spatial aliasing and contrast sensitivity in peripheral vision. *Vision Res.* (submitted).

Bradley, A., Rahman, H.A., Soni, S. and Zhang, X. (1993) Effects of target distance and pupil size on letter contrast sensitivity with simultaneous vision bifocal contact lenses. *Optom. Vis. Sci. 70*, 476-481.

Ophthalmic Optics

The widely-used interferometric method for bypassing the optics of the eye was first described over 50 years ago but has never been shown to be immune to the effects of ocular chromatic aberration. Our experiments have indicated that the polychromatic interferometer is likely to suffer markedly from chromatic aberration in the eye. To show the physical basis for this effect, the operation of the interferometer in conjunction with the human eye was investigated theoretically. It was shown that if the interferometer is misaligned with the visual axis of the eye then the prismatic effect of transverse chromatic aberration causes wavelength-dependent phase shifts in retinal fringes. This shift is directly proportional to the magnitude of the longitudinal chromatic aberration of the eye. The net effect is a significant loss of retinal contrast for polychromatic fringes which can lead to threefold loss of visual acuity.

Manuscripts

Thibos, L.N. and Bradley, A. (1992) Use of interferometric visual stimulators in Optometry. *Ophthalmic and Physiological Optics*, 12, 206-208.

Thibos, LN. and Bradley A (1993) New Methods for discriminating neural and optical losses of vision. *Optom. Vis. Sci. 70*, 279-287.

Winn, B., Bradley, A., McGraw, P., Strang, N., and Thibos, LN (1993) Reverse Chromostereopsis is predicted by transverse Chromatic Aberration. *Color Science Conference,* Manchester, England.

Additional manuscripts

Atchison D., Bradley A., Thibos LN, and Smith G, (1994) Useful variations of the Badal Optometer. *Optometry and Vision Sci.* (submitted).

Atchison D., Bradley A., Thibos LN, and Smith G, (1994) Useful variations of the Badal Optometer. *Australian Optometric Meeting.*

Bradley, A and Thibos LN, (1994). Optometry Examination Review, 4th edition: Medical Examination Publishing Company. Co-authored with Locke L., Chang, F., Gerstman, D., and Pietch P. Appleton and Lange Publishers, 1994

Atchison D., Bradley A., Thibos LN, and Smith G, (1995) Useful variations of the Badal Optometer. *Optical Soc. Am. Technical Digest, vol 2 (Vision and its Applications).* (in press).

Bradley A. (1994) Improved vision with AR coated lenses. *Optometry Today* (in Press)

Bradley, A., Applegate, R, van Heuven, W.A.J., and Nair, P. (1994) FAZ enlargement and visual acuity in diabetic retinopathy. *Ophthalmol Vis. Sci.*, vol **35** ARVO, p 1395.

C. Human Visual Optics

A new schematic eye that accurately models human spherical and chromatic aberration.
Bradley, Ye, Zhang, Thibos

The optical system of the human eye represents a low-pass spatial filter at the front-end of the visual system that limits the spatial information available for vision. An accurate and computationally simple optical model of the human eye can provide a valuable tool in evaluating the relative contributions of neural and optical filters to human spatial vision. We have recently published a single surface model eye that accurately models ocular chromatic aberration. We now extended this model to reflect spherical aberrations of the eye.

Manuscripts

Thibos, LN, Ye, M, Zhang, X, and Bradley, A (1993) A new model of the human eye. *Optics and Photonics News*, Dec., 1993, p. 12.

Ye, M., Zhang, X., Thibos, L.N., and Bradley, A. (1993). A new single-surface model eye that accurately predicts chromatic and spherical aberrations of the human eye. *Invest. Ophthal. Vis. Sci.* 34 (suppl.), 774.

Measurement of ocular chromatic aberration.
Bradley, Zhang, Thibos

Longitudinal chromatic aberration (LCA) of the human eye has been evaluated extensively but there is only one published experimental attempt to measure the ocular chromatic difference of magnification (CDM). Data from that study were inconsistent with the theoretical predictions from known models, perhaps because the magnification difference between short and long wavelengths is likely to be very small (less than 1%). Nevertheless, according to Ogle, stereopsis ought to be sensitive enough to measure an interocular difference of magnification of this magnitude. Accordingly, we have examined the effect of chromatic differences in magnification on the tilt of the Apparent Frontal Parallel Plane (AFPP). Subjects viewed a tilting plane apparatus binocularly. Interocular size differences were introduced using two techniques. First, afocal magnifiers were placed in front of the right or left eyes, and secondly, different interference filters were placed in front of each eye. The experiment was designed to identify the lens magnification necessary to nullify the interocular difference in magnification caused by the chromatic differences in the two monocular images. For

example, if there is a long wavelength (e.g. 650 nm) image in the right eye, and a short wavelength (e.g. 450 nm) image in the left eye, the frontal plane appears tilted away from the right eye because the right eye's 650 nm image is larger than the left eye's 450 nm image. We determined the lens magnification necessary to cancel this tilt. Results on three subjects show: 1) Ocular CDM can be considerably less than the published theoretical predictions; 2) Unlike longitudinal chromatic aberration, large inter-subjective differences exist for CDM; and 3) CDM increases when using an artificial pupil in front of the eye. Therefore, current theoretical model eyes need to be modified in order to predict CDM. Also, because axial position of the pupil is a critical determinant of CDM, experimental use of artificial pupils can degrade peripheral retinal image quality for polychromatic stimuli.

Manuscripts

Zhang, X., Thibos, L.N., and Bradley, A. (1994) . The wavelength-dependence of retinal image size in human eyes corrected for the effects of wavelength-dependent refractive errors. *Applied Optics*, (under revision).

Zhang, X, Bradley, A, and Thibos, LN (1993) Experimental determination of the chromatic difference of magnification of the human eye and the location of the anterior nodal point. *J. Opt. Soc. Am. A 10*, 213-220.

Optical correction of chromatic aberration.
Zhang, Ye, Bradley, Thibos

Visual sensitivity is not uniform across the pupil. Sensitivity peaks near the pupil center and is reduced at the pupil margins (Stiles-Crawford effect or SCE). Is there any functional advantage derived from this property? The SCE can be considered equivalent to apodization of the pupil, but no functional value of this apodization has been observed for well-focused images 1-3. However, the most significant effect of SCE may be to increase depth of focus. Using a wave-optics model of the human eye, we incorporate apodization by changing the pupil transmission function from a uniform function into an SCE function. We calculate the influence of SCE on the OTF with defocus error or ocular spherical aberration. Our results show that (1) Stiles- Crawford apodization significantly improves contrast for defocused images for large pupils, and (2) The Stiles- Crawford apodization is also effective at improving image quality when the eye exhibits significant spherical aberration.

Manuscripts

Ye, M., Bradley, A., Zhang, X., Thibos, L.N. (1992) The effect of pupil size on chromostereopsis and chromatic diplopia: Interaction between the Stiles-Crawford Effect and chromatic aberration. *Vision Research* , 32, 2121-28.

Winn, B., Bradley, A., Strang, NC, McGraw, P., and Thibos, LN. (1994) Reversals of the color depth illusions explained by ocular chromatic aberration. *Vision Res.* (submitted)

Retinal image quality and visual performance.
Thibos

The reduced schematic eye (the "water eye") accurately describes the magnitude of both transverse and longitudinal chromatic aberration of the human eye. The modulation transfer function (MTF) of this model, including the effects of diffraction, is easily calculated for monochromatic light and the results integrated across wavelength to produce a white-light MTF. We investigated how sensitive this MTF is to changes of wavelength-in-focus (i.e., the mean refractive error) and to changes in pupil diameter for a typical (2800 K tungsten) white source. The results indicate that both parameters have significant impact and clear maxima exist. For this source, 570 nm is the optimal wavelength-in-focus for any pupil diameter and a 3mm pupil is optimal for any wavelength-in-focus. These results are understandable as follows. Although the model is emmetropic for 590 nm, the weight of the luminous efficiency curve shifts the optimal wavelength-in-focus towards shorter wavelengths. The optimal 3-mm pupil balances the tradeoff between the effects of diffraction for small pupils and chromatic blur for larger pupils.

Psychophysical localization of the human visual streak.
R. S. Anderson, M. O. Wilkinson, L. N. Thibos

Several topographical studies of the human retina have revealed the presence of a weak 'visual streak'. Curcio and Allen (1990, *J. Comp. Neurol.*, 300, 5.) describe the visual streak as a prominent nasotemporal asymmetry in ganglion cell density at eccentricities beyond the optic disk, such that the ganglion cell density of the nasal retina is at least three times that of temporal retina. The obvious implication of their results is that the asymmetry in density, as measured anatomically, will yield measurable asymmetry in any visual function which is limited by ganglion cell density. Peripheral resolution acuity is thought to be limited by spacing of retinal ganglion cells (Thibos et al., 1987, #16) and therefore should reflect the anatomical asymmetry in the retina, provided the attenuating effects of the eye's optics are minimized. We tested this hypothesis directly by employing an interferometer to map resolution acuity as a function of retinal meridian for patches of sinusoidal grating (2.5 deg., 550 nm) placed at 25 degrees eccentricity. To ensure that performance was sampling limited, subjects reduced spatial frequency until aliasing vanished and veridical perception of grating orientation was achieved. Acuity for the two subjects was higher on the horizontal nasal meridian (5.8 to 6.6 cpd) than on the other seven meridia (1.4 to 3.2 cpd). Analysis of orientation bias revealed slightly higher acuity for gratings oriented radially. Our results indicate that the human visual streak can be localized psychophysically by using a sampling limited resolution task. The visual streak is manifest as higher acuity values on the nasal horizontal meridian as compared to other retinal locations of the same eccentricity. Sensitivity of this technique suggests it has potential as a non-invasive method for assessment of ganglion cell topography in the human retina.

Color-contrast modulation transfer functions and the effect of ocular chromatic aberration.
Thibos, Zhang, Bradley, Ye

To be complete, models of color perception, spatial vision, accommodation, and many other visual functions require knowledge of how the eye's chromatic aberration affects the color contrast of retinal images. This in turn requires specification of the modulation answer functions (MTFs) of the eye for each of the 3 cone types (L,M,S). Determining such MTFs is analogous to determining the

luminance MTF of the eye for polychromatic stimuli. That problem was solved by using an optical model of the eye to compute the monochromatic MTF for a number of different wavelengths, weight each by the luminance efficiency curve (Vl) and integrate over wavelength (Thibos et al., 1990). The same method was used to solve the current problem by substituting for Vl the fundamental sensitivity curves of the L, M, and S cones (Vos Walraven fundamentals, as tabulated in Wyszecki and Stiles [1982, Color Science, 2d ed., p. 614]). The results show that for a typical white light source (P4 phosphor) image quality cannot be optimized simultaneously for all three cone types. Maximum L-con contrast occurs when the wavelength-in-focus is 570nm, but this optimum wavelength shifts to 550nm for the M-cones, and to 470nm for the S-cones. This 100nm spread corresponds to a relatively large, 0.6 diopter refractive error which can have major impact on image contrast. For example, if 470nm is in focus then S- cones enjoy maximum image contrast but L- and M-cones will suffer up to 2 log units of contrast attenuation (at 20 c/d; 1 log unit at 10 c/d) due to longitudinal chromatic aberration. Such large optical effects would be expected to significantly affect post-receptoral mechanisms sensitive to color contrast of spatial patterns.

Neural basis of scotopic acuity.
M. O. Wilkinson, L N. Thibos, A. Bradley

Evidence from several primate studies suggests that the magnocellular (M) pathway supports scotopic vision due to the inability of the parvocellular (P) pathway to respond to patterned stimuli below 1 phot. Td. (Purpura et al., 1988 [*Proc. Natl. Acad. Sci.*, **85**, 4534]). However, Fairchild and Lenie (1988 [*OSA Tech. Digest Series*, **11**, 80]) found human scotopic resolution limits too high to be supported by the M pathway. They also failed to find aliasing, which led them to conclude that scotopic resolution is limited by the size, not spacing, of P cell receptive fields. However, the attenuating effects of the eye's optics may have rendered their task contrast- limited which would have prevented the detection of aliased patterns. We tested this hypothesis directly by employing an interferometer to avoid optical limitations. Resolution limits were set for patches of sinusoidal gratings (0.1 phot. Td. at 505 nm) of variable eccentricity along the horizontal meridian in the temporal retina. Subjects reduced spatial frequency until veridical perception of grating orientation was achieved. Mean scotopic resolution limits were 8.2 cpd at 5 degrees and declined with eccentricity to 1.5 cpd at 40 degrees. For several subjects, there was no significant difference between photopic and scotopic acuity and for others scotopic acuity was only slightly worse. Aliasing was reported by all subjects, which confirms that the resolution task was sampling limited. One subject confirmed aliasing at 0.01 phot. Td., which was only 1.5 log units above absolute threshold. Our results support Fairchild and Lennie's (1988) conclusion that scotopic acuity is too high to be supported by the M pathway and therefore must be carried by the P pathway. However, contrary to their results, our observation of aliasing for spatial frequencies up to 50% beyond the resolution limit indicates that it is the spacing, not the size, of the P cell receptive fields that limit scotopic resolution in the human peripheral retina. The reduced scotopic acuity indicates that the less sensitive P cells may drop out as luminance decreases, thus reducing the effective sampling density. (This project was supported by N.I.H. EY05109.)

The chromatic eye: A new model of ocular chromatic aberration.
L. N. Thibos, M. Ye, X. Zhang, and A. Bradley

The optical apparatus of the eye presents a low-pass spatial filter to the front end of the visual system which is a potential limiting factor for any visual task. In the well focused eye, chromatic

aberration and diffraction are thought to be the major optical factors limiting vision (van Meeteren, 1974 [A. Ophca Acta, 21, 395-412]; van Meeteren, A. and Dunnewold, CJ.W., 1983 [*Vision Res.*, **23**, 573 -579; Thibos, L.N., Bradley, A. and Zhang, X., submitted [*Optom. Vis. Sci.*]). Consequently, it is important to have available an accurate, mathematically tractable model of ocular chromatic aberration to help gauge the potential magnitude and significance of these optical effects for visual performance.The principle of the two-color vernier method (Thibos, L.N. et al., 1990 [*Vision Res.*, **30, 33** 19; Ivanoff, A. C. R., 1946 [*Acad. Sci.* (Paris), **223**,170- 17y) was used to measure focussing errors of the eye. A subject viewed a vertically oriented, vernier target in which the upper bar was fixed in space and illuminated with light of reference wavelength 555 nm. The lower bar of the target could be displaced horizontally and was illuminated with a variable wavelength source. The subject viewed this target through a pinhole aperture which was attached to a micrometer for precise positioning by the experimenter. The subject's task was to align the two-color vernier target by physically misaligning the lower bar in compensation for the chromatic difference of position. In the context of the reduced-eye model, the amount of defocus of the eye for the given test wavelength is given by the rate of change of vemier offset with pinhole displacement (Thibos, L.N. et al., 1990 [*Vision Res.*, **30**, 339; Ivanoff, A. C. R., 1946 [*Acad. Sci.* (Paris), **223**,17172]). The data provide a reliable new assessment of the variation of refractive error of the human eye across the visible spectrum. These results are accurately described by a reduced-eye optical model which has a refractive index which changes more rapidly with wavelength than occurs for the water-eye model. To distinguish it from the water-eye, we have dubbed this new reduced-eye model of ocular chromatic aberration the "chromatic eye."

D. Event Perception and Perception in Relation to Head Movement.

Visual perception of lifted weight.
Bingham

Observers viewing displays created by filming people lifting weights from 5 lb to 65 lb so that only bright patches attached to the major limb joints can be seen in the displays have been shown to be able to judge the amount of weight lifted. The natural question is how mere motions can provide visual information for amount of lifted weight. The original studies used standard displays in which observers where told the amount of weight lifted. We have replicated these studies without standard displays demonstrating that they are not required for the result. Further, we have varied the size of the lifters from 115 lb to 190 lb in displays containing no static information for lifter size (e.g. image size of patches or the distribution of patches) and varied the range of weights lifted by each lifter and shown that observers remain able to judge lifted weights. This implies that the motions provide information for lifter size. Current experiments are investigating this possibility.

Perceiving the size of objects in events
Bingham

Traditional solutions to the problem of size perception have confounded size and distance perception. We investigated size perception using information that is independent of distance. As do the shapes of biological objects (Bingham, 1992), the forms of events vary with size. We investigated whether observers were able to use size specific variations in the kinematic forms of events as

information about size. Observers judged the size of a ball in displays containing only kinematic information about size. This was accomplished by covarying object distance and actual size to produce equivalent image sizes for all objects and extents in the displays. Simulations were generated using dynamical models for planar events. Motions were confined to a plane parallel to the display screen. Mass density, friction, and elasticity were held constant over changes in size, simulating wooden balls. Observers were able to detect increasing size of the ball. Mean judgments exhibited a pattern predicted by a scaling factor in the equation of motion derived using similarity analysis.

Visual perception of tree size.
Bingham

Two aspects of the shape of trees are constrained by scaling laws that produce a relation between tree size and tree shape. We have been investigating tree shape as information about tree size by producing tree silhouettes via computer graphics simulations that have been borrowed from research in tree morphology and that model the physical processes underlying the relevant scaling laws. Observers have been asked to judge tree height merely from the silhouettes, all of the same image size and without any background structure. Results compare favorably with results when the same observers were asked to judge the height of real trees observed around the campus. We next placed the tree silhouettes in the context of a ground texture gradient together with a set of cylinders of varying size placed at various locations within the gradient. The problem with either ground texture gradients or motion parallax fields is that neither provide information for absolute scale. Only the relative sizes and distances of objects within the field can be determined. We investigated whether the trees might confer an absolute scale on a ground texture gradient. This possibility was confirmed by our results. Observers were able to estimate the size of the cylinders when they appeared in the context of the trees, but not without the trees.

Visual identification of events
Bingham

People are able to perceive and recognize events. How might event structure and corresponding information about events be described? We have developed 'optical phase space' as a possible description and as a way to illustrate both the nature of events as objects of perception and the problem of mapping from event structure to optics. Optical phase space yields enough structure to allow us to analyze the identification of such dynamical properties as rigidity, elasticity, plasticity, and liquid flow. The importance of event dynamics in determining the perceptual significance of motions in events was investigated. Patch-light displays were recorded for 9 simple events selected to represent different kinds of dynamics including rigid body dynamics, biodynamics, hydrodynamics, and aerodynamics. Observers of the displays described the events in both a free response task and in tasks in which observers circled properties in a list. Results of cluster analyses performed on frequencies for descriptors reflected the underlying dynamics rather than crude kinematic similarities among the displays. Observers discriminated animate versus inanimate versions of rigid body events where only the form of the phase trajectories differed. Three viewing conditions were used as a between-subjects manipulation including upright displays and observers, inverted displays and upright observers, and upright displays and inverted observers. Perceived event identities varied with the absolute orientation of the displays with respect to gravity, but were unaffected by the relative orientation of display and observer. Finally, the event kinematics were measured and investigated as

the source of information for event identities. A force-choice task confirmed the ability to discriminate animate motions based only on the form of phase space trajectories. The dynamics of these events was modeled to discover the properties which revealed animate activity.

Optic flow generated by eye movements.
Bingham

As the point of perspective moves in cluttered surroundings optical texture is revealed or hidden at boundaries corresponding to occluding edges. The point of perspective in the eye is located near the lens and pupil at a distance of about 11mm from the center of rotation of the eye. Thus, even with the head immobilized, the point of perspective moves as the eye is rotated during eye movements. The resulting accretion or deletion of optical texture occurs at optical boundaries which sweep across the retina in phase with the accretion/deletion. Can observers detect such optical flows? Five observers were tested in monocular viewing. OU's head was immobilized via a biteboard with the center of rotation of the right eye located at the intersection of centerlines extended from 2 optical benches, one lying along the line of gaze parallel to the sagittal plane of the head (straight ahead) and one lying along a line of gaze at a visual angle from straight ahead of either 20!, 30!, or 40! nasalward. Two white surfaces were adjusted via translation platforms with micrometers so that a red area on the rear surface was just occluded by the left edge of the front surface as O looked straight ahead. The amount of red texture revealed and detected as O looked nasally at a target located on the second bench was measured by translating the rear surface to the right until the texture was no longer detected by O (method of adjustment). Twelve configurations of surface distances were tested with the three angles of eye rotation. Predicted visual angles of revealed texture somewhat overestimated measured angles. A subsequent test with four OU's using a criterion-free signal detection method at two configurations of the surfaces revealed that the texture could be detected up to the predicted angles. Finally, we investigated whether this information could be used to detect the separation of surfaces in depth. We found that observers could distinguish separated from flat surfaces, but they could not detect which surface was closer.

Object shape as visual information about the center of mass.
Bingham

Grasps are often organized and located with respect to the center of mass in an object. The stability of a precision or pincing grasp is determined by where the axis extending between opposing pincers passes with respect to the center of mass. An axis above the CM results in stabile equilibrium while one below is unstable. Passing the axis through the CM results in neutral equilibrium such that the object will remain at any orientation in which it is placed by rotating about the axis. How might observers visually assess the location of the CM preparatory to a grasp? We investigated symmetry properties as information in planar objects. Objects with from 0 to 4 axes of reflective symmetry as well as objects with various periods of rotational symmetry were used. Observers were asked to place the points of a set of tongs at the location at which that would grab the object to achieve neutral equilibrium in a grasp. The orientation and the size of the objects were also varied. Random errors were significantly affected by both size and symmetry. Systematic errors were affected orientation. Additional studies were performed to investigate information used in the absence of symmetry.

Sensorimotor learning in reaching with vision through a displacement prism
Bingham

Observers reaching to a target seen through wedge-shaped displacement prisms initially reach in the direction of displacement, correcting their reaches over a series of about 12 trials. With subsequent removal of the prisms, observers initially reach to the opposite side of the target, correcting over about 6 trials. This phenomenon has been called "adaptation" because of its similarity to the adaptation of sensory thresholds to prevailing energy levels. We show, however, that this perturbation to visually guided reaching only mimics sensory adaptation initially. Subsequent changes show that this is sensorimotor learning. Error in pointing to targets is the commonly used measure. We measured times for rapid reaches to place a stylus in a target. Participants wearing a prism worked to achieve criterion times previously established with normal, unperturbed vision. Blocks of trials with and without a prism were alternated. Both the number of trials to criterion and the mean times per block of trials decreased over successive blocks in a session, as well as over successive days. By the third day, participants were able to respond rapidly to perturbations. This reflects the acquisition of a new skill that must be similar to that acquired by users of corrective lens.

Manuscripts and abstracts

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Bingham, G.P. (1993). Perceiving the size of trees: Biological form and the horizon ratio. *Perception & Psychophysics.* **54**,485-495.

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Bingham, G.P. (1995). Dynamics and the problem of visual event recognition. To appear in Port, R. & T. van Gelder (eds.), *Mind as Motion: Dynamics, Behavior and Cognition.* Cambridge, MA: MIT Press.

E. Color Vision

Theory and data concerning color perception and visual adaptation.
Guth

A model for color perception and visual adaptation has been developed by Dr. Guth with full support from the Institute. The model and its revisions have been published as a major paper in the *Journal of the Optical Society of America*, and it represents an important advance in the visual sciences. That is, given the physical specification of a light, the model allows predictions of the light's detectability, brightness, hue and saturation. Also, the model will predict if the light will be discriminably different from other nearby lights of background fields, and it can make these predictions for vision under a very wide range of chromatic and achromatic adaptation conditions.

Recent work on the model has allowed it to make predictions over an increased range of luminance levels, and it is now presented in a form that makes it more accessible to lighting and imaging engineers for use in the applied sector.Questions that emerged from the model have concerned (i) whether or not the stimulus that appears as a perfect white (*i.e.*, completely achromatic) varies with intensity level, and (ii) whether complex color contrast effects can be modeled using simple averaging rules. Both of these questions are being studied with graduate student T. Petersime. Experiments with Mr. T. Petersime (a graduate student) show that the perception of "unique" white is indeed invariant with intensity changes. (The model has been modified to reflect this fact.)

Manuscripts

Guth, S.L., (1994) ATD model for color vision I: background. *Proc. SPIE -- The Int. Soc. Opt. Engr., 2170*, 149-152.

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V. Bioacoustic Research

Effect of unilateral denervation on the acoustic output from each side of the syrinx in singing mimic thrushes.
Suthers, Hartley

Microbead thermistors implanted in each primary bronchus of adult male catbirds (Dumetella carolinensis) and brown thrashers (Toxostoma rufum) were used to record the acoustic contribution from each side of the syrinx before and after unilateral denervation of the syringeal muscles. Thermistors responded to air movement produced by the vibrating syringeal membranes. In these birds, paralysis of the muscles on either side of the syrinx resulted in an abnormal song, but the effect was usually slightly greater after the left side was paralyzed. Denervation of either the left or right side of the syrinx increased the number of syllables to which that side contributed sound. Few or no syllables were produced by the intact side alone and most post-operative syllables contained simultaneous contributions from both sides of the syrinx. The sound generated on the denervated side usually consisted of a fundamental with an abnormally low frequency and multiple harmonics. The frequency of this fundamental typically paralleled changes in the rate of airflow on that side of the syrinx, which in turn followed changes in the driving subsyringeal pressure. Sound from the intact side was essentially normal. The abnormal post-operative song in these birds is primarily due to their inability to regulate resistance or membrane tension on the operated side of the syrinx. We postulate that since the denervated side can no longer be silenced by adduction, its relaxed medial tympaniform membrane vibrates at a frequency determined by the rate of airflow across it.

VI. Cognition and Decision Making

Attention, automatism, and skill learning.
Shiffrin

Nancy Lightfoot and I are continuing research on perceptual learning and automatic processing. Several articles and papers have appeared on this topic (Shiffrin, Czerwinski, and LKightfoot, 1993; Czerwinski, Lightfoot and Shiffrin, 1992; Lightfoot and Shiffrin, 1992) and others are in preparation. We have constructed novel visual characters so that they would tend to consist of three separate and independent visual features; we then demonstrated experimentally that this representation was correct. During extensive training in which subjects searched for one of these characters in a visual field of others, the rate of search improved by an order of magnitude (a most surprising finding since for known characters the rate of search usually doesn't change with training, no matter how extensive). We demonstrated that the separate features of the novel stimuli gradually came to cohere into a single perceptual unit, over from 15 to 35 sessions of training depending on the visual similarity among the characters. We have shown what sort of training is required for this unitization to occur, which features join the unit, and which do not, and what sort of generalization from the new unit takes place. We believe the unitization demonstrated in this paradigm is a much more accurate representation of the visual object learning encountered in normal experience than previous measures such as Treisman's zero slope criterion, or Garner's tests for configurality.

In a second project, Nancy Lightfoot and I are developing a model for visual search incorporating interitem similarity, based on careful scaling of the stimulus set (alphabetic characters), and elucidating the roles of attentive and automatic processing. The studies have been carried out, and some modeling completed, showing that the similarity of targets to distractors is critical, but that the similarity of distractors to each other plays no role (except for the case of homogeneous displays in which all characters are identical; search through such displays is accomplished by more primitive visual mechanisms, and this is therefore a special case). This work is not yet published.

In a third project, Asher Cohen, David Diller, Michael Fragassi and I have been exploring the degree to which visual information is processed from one part of the visual field during the time period that attention is focused on another part of the visual field. One part on this work was presented at the 1992 Psychonomic Society meetings, and a chapter covering another set of studies was published in Shiffrin, Cohen, and Diller (in press). We discovered that processing from distant unattended locations does take place, but does not enter into processes that affect performance until the subject subsequently directs attention to the previously unattended location. In addition, the rapid forgetting of such unattended information makes it most tricky to demonstrate such effects because the information tends to be gone by the time attention moves to the previously unattended location. An appreciation of this state of affairs helps to disambiguate a very confusing literature on attention effects and the relation to automatic processing.

In a fourth project, Shiffrin (in press) carried out a criticAl theoretical analysis of the relation of the attention/automatism distinction to the consciousness/unconsciousness distinction. It was demonstrated that these are not parallel distinctions, and differ in many fundamental ways.

Short term Memory
Shiffrin

Shiffrin (1993) reviewed contemporary research on short-term memory, highlighting its fundamental and generally accepted role in memory theories, and its function in explaining a wide variety of data. Shiffrin and Nosofsky (1994) used a review of Miller's classic article on the "Magic Number Seven" to discuss the theoretical interplay among attention, short term memory and long term memory, and the relation of these to capacity limitations in cognition.

Memory and retrieval.

We have continued several projects examining the nature of memory storage, retrieval and forgetting. Shiffrin and Murnane (1991) summarized data showing that interference arises at retrieval rather than storage. Murnane and Shiffrin (1991a) ruled out differential rehearsal as an artifactual explanation of the findings underlying this conclusion. They fit a model to the data, illustrating how sentence memory and forgetting could be accounted for with a differentiation version of a global familiarity model. Murnane and Shiffrin (1991b) used a technique of comparing retrieval immediately after list presentation to retrieval at the end of an experimantal session to demonstrate the necessity of a model with separate storage of episodic images, and the necessity of a model with a concept like differentiation. Clark and Shiffrin (1992) showed how cues could act in combination and separately to govern retrieval from memory. Shiffrin and Raaijmakers (1992) described the current status of the SAM model for memory storage and retrieval, and some of its notable recent successes. Raaijmakers and Shiffrin (1992) critically reviewed, contrasted, and evaluated the current status of models of memory.

In recent research, Huber, Ziemer, Shiffrin and Marinelli (1992) and Shiffrin, Huber, and Marinelli (in press) asked whether memory activation rises with changes in the number of items added to memory, or the strength of items added to memory. They used a long list of exemplars from many categories to show that activation rises with added items, but stays constant with added strength, consistent with the differentiation version of the SAM retrieval model, as shown by excellent fits of the model to data.

Richard Shiffrin and Dave Huber have carried out theoretical research exploring models of retrieval in which separate traces that become active send inhibitory signals to each other in certain circumstances. The new model is used to explain certain seemingly inexplicable findings concerning the failure of repeated items to cause forgetting. This research was reported at the 1992 Mathematical Psychology Meetings, but is still continuing and is not yet published.

Memory and learning
Shiffrin

Peter Nobel and I are continuing a long project on response times in recall and recognition, using free response and signal-to-respond techniques. We have extensive data suggesting that different retrieval processes underlie recognition and cued recall behavior (Nobel and Shiffrin, 1992). Other studies have shown that associative recognition obeys retrieval laws that are more similar to those constraining cued recall than those constraining recognition, if signal-to respond techniques are used, but more similar to recognition if free response techniques are used. Models within the SAM framework have been developed and applied successfully to cued recall, free response, to cued recall,

signal to respond, to associative recognition, free response, and to associative recognition, signal to respond.

Perhaps the most interesting findings occurred in recognition, since we obtained the strong and unexpected finding that list length and study time strongly affected response accuracy, but did affect response time at all. To be precise the conditional distributions of response times for hits, correct rejections, false alarms and misses each did not change with list length or study time for the list. We developed a new model based on stimulus sampling and stimulus fluctuation that did a remarkably fine job of predicting both accuracy and response times in all our conditions. We also extended this model to signal-to-respond data in recognition. Most of this research is presently being prepared for publication.

Larissa Samuelson and I have examined the role of context cuing in recognition, finding dramatic differences when retrieval is directed toward older as opposed to recent memories. This work is being prepared for publication.

Manuscripts

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Dynamic field theory of decision making.
Townsend

Over the past year, my colleagues and I made progress on a dynamic field theory of decision making in collaboration with Jerome Buremeyer of Purdue University. This mathematically expressed theory begins establishing a more biologically and psychologically realistic view of decision making. It moves away from the rather static utility theory conception that has been traditional since the work of von Neumann and Morgenstern in the 1940s. Application of the theory to classic experimental paradigms as well as some designs that are better able to exploit the new framework has begun.

Manuscript

Busemeyer, J., & Townsend, J. R. (1993). Decision field theory: A dynamic-cognitive approach to decision making. *Psychological Review,* **100**(3), 432-459.

Presentation

Townsend, J. T. (1993). Invited Address by F. G. Ashby of University of California - Santa Barbara: Decision bounds and identification and categorization. *Twenty-sixth Annual Mathematical Psychology Meeting.* August, 1993; Norman, OK.

General recognition theory: parallel vs. serial processing.
Townsend

Development of the General Recognition Theory (of F. Gregory Ashby and J. Townsend) in collaboration with Helena Kadlec of Purdue University has continued. This work synthesizes Townsend's laboratory's previous methodologies using signal detection theory with multi-feature displays and the Ashby and Townsend theory with regard to perceptual independence and separability.

Manuscripts

Kadlec, H., & Townsend, J. T. (1992). Signal detection analysis of multidimensional interactions. In F. G. Ashby (Ed.), *Probabilistic Multidimensional Models of Perception and Cognition.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Townsend, J. T., & Thomas, R. Stochastic dependencies in parallel and serial models: Effects on systems factorial interactions. In press. *Journal of Mathematical Psychology.*

Self-terminating vs. exhaustive processing
Townsend

Theoretical development of tests of self-terminating vs. exhaustive processing has continued (i.e., can a very rapid processor, e.g., a "reader", stop when sufficient information has been gained for a response or must it proceed until all items have been processed?).

Manuscript

Van Zandt, T., & Townsend, J. T. (1993). Self-terminating vs exhaustive processes in rapid visual, and memory search: An evaluative review. *Perception & Psychophysics,* 53(5), 563-580.

Manuscripts and abstracts

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Presentations

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Comments on linear models: Implications for the lens model
Castellan

Linear models are widely used to evaluate decision strategies. While some research has been done to show that linear models of various types (regression, equal-weighting, etc.) can give good accounts of performance, most such studies have been simulation studies. This research analyzed the relations between models and bounds for such relations were found and evaluated.

Shuffling arrays: appearances may be deceiving.
Castellan

In experiments and tasks involving the presentation of complex information and in simulations, it often is necessary to permute arrays of data (or stimuli). Although the properties of random number generators have been analyzed extensively, it appears that permutation algorithms have been given only cursory examination. This paper analyzed two widely published permutation algorithms and found that while one does shuffle an array appropriately, the other introduced systematic and serious bias into the permuted sequences. Such bias could have serious implications for research which relied on such an algorithm for shuffling or permuting arrays. (Manuscript submitted and accepted subject to revision.)

Human factors in computer-based instructional modules.
Castellan, Lamblin

There is widespread use of computer-based instruction in undergraduate education. Software written for this purpose varies widely in the user interface. It is the purpose of this project to evaluate a variety of instructional software from the view of Human Factors design. This evaluation, while comparative, will lead to a final report in which specific recommendations may be made concerning the design of the user interface in computer-based instruction.

Individual and group decision making.
Castellan

Much research has been done on the comparison of individual and group decision making. One seeming paradox which has frequently been reported in research on the problem is that in binary decision tasks, a group may make a different decision than the individuals. (That is, individuals may prefer alternative A, but the group may prefer alternative B.) Many psychologists have worked hard to develop models concerning how the interaction among the members of a group can lead to such reversals. Analytical analysis of the problem has begun and an explanation has been developed for such reversals that does not depend upon group interaction, but a simple pooling of resources. It is too early to tell the full implications of this work, but it suggests that group interaction may involve much less complex processes than some theories allege. A preliminary report on this will be completed in the Spring of 1991.

In addition to these projects, work is continuing on two other long-term projects involving the use of information in decision making. One involves the manner in which information is combined in

complex judgment tasks, and examines the conditions under which judgment can be construed as a simple additive or cumulative process, and conditions in which information is combined in complex, interactive ways. The other involves the evaluation of witness credibility when either conflicting or collaborative testimony is also available. Preliminary reports on these projects were given at the Midwestern Psychological Association meeting in May 1990.

VII. Connectionist Models of Sensory and Cognitive Processes

Recognition of tone sequences by dynamic connectionist models.
Port, Anderson

We are building functional models that can directly process auditory information in time. We employ recurrent networks, that is, networks with many recurrent or feedback connections. These systems 'reverberate' to sequentially presented input patterns that they have been trained to respond (Port, 1990). We believe there may be significant similarities between subject performance on well-learned auditory patterns (Spiegel and Watson, 1981; Leek and Watson, 1988) and the behavior of our recent simulations (Port, 1990; Anderson and Port, 1990). We call the clique of reverberant nodes the ones that recognize the pattern by tracing a trajectory of activation states which lead to a final state that is distinct for each learned sequence Dynamic Memory. This model constitutes an implemented hypothesis about the form of representations used by human listeners when they have learned a complex auditory pattern well. By comparing the performance of various forms of dynamic memory on various tasks with the performance of human subjects (where it is known), we should improve our understanding of human processing of temporal patterns.

Network architectures.
Port

Our networks have a set of input nodes corresponding to the channels of a bank of filters. Melodylike patterns are presented, a spectrum slice at a time. The Dynamic Memory is the next layer of nodes which are fully connected. Its recurrent connections store information about the history of the signal after the training process. The specific response trained into the system was for one of these nodes to produce maximum output for the last two time frames of each target pattern. The gradient-descent teacher-driven learning algorithm we use is known as Recurrent Backpropagation (Wllliams and Zipser, 1990). This algorithm can be used with fully connected networks such as the Dynamic Memory.

Formal properties of cognitive representations.
Port, van Gelder

Since September, 1990, Timothy van Gelder (Philosophy) and Port have been investigating general properties of cognitive representations from a global and philosophical perspective. Their goal is to spell out a conceptual framework for representations in which the traditional formal structures of cognitive science (such as 'perceptual features', classical categories, 'frames', 'declarative data structures', etc.) and the 'distributed representations' of connectionist models (Smolensky, 1988; van Gelder, 1990) can both be seen as special cases. Difficult problems arise if dynamic temporal patterns, such as those employed by Watson (Spiegel and Watson, 1981; Leek and Watson, 1988) or illustrated in our dynamic memories (Port, 1990) are employed as the primitive atoms of a 'symbol' system. How can such primitives compounded into complex units? It appears to us that representational systems can be compared along 3 primary axes. (1) What are the formal properties of the atoms of the system? In particuLar, are they dynamic or just static vectors? (2) How does compounding of tokens take place? Concatenation, superimposition (Pollack, 1990), or what? And (3) what is the functional role of the symbol-like units? That is, how is control of the executing system managed — from the top down or partly from the bottom up? Our work on this problem will lead to an essay that will

attempt to clarify the relationship between the older-style of artificial intelligence (which assumed symbolic primitives) and the new cognitive science. The new cognitive science, in contrast, eschews naive assumptions about static atoms of complex representations. Instead, much more sophisticated dynamic models for sensory processes are relied upon.

A connectionist approach to the acquisition of morphophonemic rules.
Gasser

Work during the past year has focused on modeling the learning of the ability to recognize polymorphemic words formed with a variety of morphological rules. It has been shown that separate network hidden layers responsible for root recognition and inflection recognition improves performance dramatically. This provides a new argument for the division between lexicon and grammar which is a part of conventional models of language processing and acquisition.

Modeling the development of the concept of sameness.
Gasser, Smith

Recent work with our network model of lexical learning has focused on isolating factors which lead to the advantage of nouns over adjectives in early lexical learning. Categories which encompass relatively large and compact regions in representational space are learned faster, categories which are elicited with questions about dimensions ("what color is it?") are learned more slowly than those which are not ("what is it?"), and types of categories for which there are more members to be learned are learned more slowly. The first three of these factors favor nouns, the last adjectives. Our experiments show that accounts of the noun advantage do not require prior knowledge of the noun-adjective distinction.

Dynamic short-term auditory memory by connectionist models
Robert Port, Devin McAuley, Sven Anderson, Joseph Stampfli
Department of Linguistics, Department of Computer Science, Department of Mathematics

We are building functional models that can directly process auditory information in time. We employ recurrent networks, that is, networks with many recurrent or feedback connections. This portion of the overall project attempts to construct a memory that simulates human `sensory trace memory' for auditory intensities in various frequency ranges. It is an extension of the model proposed by Zipser (1991). The model stores the intensity of an input tone for a period of time and gradually decays (`forgets') the tone intensity. The resulting sensitivity of the model to stimulus-onset asynchrony for a roving intensity discrimination task has been demonstrated for human listeners on a similar task (Berliner and Durlach, 1973). We have studied the dynamic behavior of this model under varying conditions of internal noise and have undertaken mathematical analysis of the model as well. A surprising discovery is that under certain conditions the presence of noise actually improves the performance of the memory. Our research has explored the nature of those conditions.

Temporal pattern recognition with networks
Sven Anderson, Devin McAuley, Robert Port, Fred Cummins and Joseph Stampfli

A number of additional simulations were conducted during this year plus the development of Anderson's dissertation project. The stimuli were simulated tone sequences presented as 8-step patterns as though the FFT frames of sinusoids -- thus in connectionist terms, they were orthogonal input vectors, in some cases with significant amounts of added noise. In one simulation, our fully recurrent network was fed randomly ordered measures in a stream and trained to recognize occurrences of the two target measures. Even with a signal/noise ratio (per individual frame) of 0 dB, the system could distinguish two target sequences from the nine other competing sequences with d' larger than 2.0. This is good performance and suggests that, despite the limitation of being unconstrained in architecture, this approach may be useful as a model of rate-invariant and noise-resistant pattern recognition. Dynamic memory allows the input pattern itself to entrain the response of the network. Apparently this system is robust enough to handle considerable natural variation in inputs. This is a step toward a continuously functioning dynamically controlled perceptual system for auditory patterns. In Anderson's dissertation work, he has developed more constrained architectures that self-organize to recognize common acoustic sequences in the sounds presented to the model. Employing Grossberg-like shunting equations in cliques of inhibitory clusters, the model can learn sound patterns of apparently arbitrary complexity.

Recognition of rhythmic patterns
J. Devin McAuley, Robert Port, Michael Gasser

Rhythmic patterns present another important subclass of sounds for analysis. Proper response of a model show be the ability to recognize a rhythmic pattern despite changes in rate and the ability to predict when subsequent events from the pattern will occur. Developments this year include a system that quickly `learns' to respond at the correct rate when stimulated with pulses at a regular periodicity. This project will become J. D. McAuley's thesis project. Other simulations using a fully recurrent network demonstrate that in simply learning a sequence, the model will discover if patterns have any periodicities in them. If they do, these periodicities will be exploited by the model to differentiate targets from nontargets.

Listening experiments with tone sequences
Kidd, Rogers, Port, Watson, Anderson, McAuley

This year we conducted 2 experiments on minimal or low uncertainty tone-sequence perception. The experiments are extensions of the Spiegel and Watson (1981) experiments using tone patterns that are very familiar. Subjects are given considerable training on a single tone pattern at a time and asked to discriminate changes in one tone in each pattern. After training one tone in a pattern, we probed subjects' ability to resolve changes in both the target tone and other tones in the pattern. Our results show that when listeners know a pattern well, they are just about as good at detecting changes in non-target tones as in the target tone -- no matter whether they were trained for a particular target, for multiple target tones or simply for identification of the pattern as a whole.

Temporal microstructure in speech perception
by R. Port, Juan Pablo Mora, Catharina de Jonge, Sven Anderson

Many experiments on lexical minimal pairs have demonstrated the role of timing in the identification of words. Other work on less well controlled contexts suggests that temporal information may not be very useful for ordinary perception due to the large degree of variation from uncontrollable contextual features. We have two subprojects for which primary data collection was done in previous years but manuscript development has continued.

First, in a series of experiments using simplified speech-like non-speech stimuli whose temporal structure is based upon natural utterances, we have demonstrated that native speakers can identify words much better than nonnative listeners. Furthermore, we found to our initial surprise that a simple linear discriminant function using the vector of segment durations for a set of 30 tokens each of 3 English words was able to identify the words far better (88% correct) than native listeners (58% correct) as well as a group of Spanish speakers who speak English with a foreign accent (43% correct). There are two places to look for an explanation of this effect. The less likely possibility is that the human listeners found it impossible to optimize the combination of the durational measurements from each token. The more likely explanation, in our view, is that the human listeners are unable to simply measure the durations of the segmental intervals in these stimuli very well.

Second, Anderson and Port explored the possibility of exploiting temporal detail to directly identify suprasegmental features of words and phrases from the temporal properties of measurable segmental units.

Models for general and temporal human cognition
R. Port and T. van Gelder

An important idea seems to have emerged independently in many areas of cognitive research. This is the use of dynamic models for the representation of cognitive objects. Dynamic models have been proposed for such diverse cognitive phenomena as perceptual differentiation of scents, motor control of the limbs, linguistic control of the articulatory apparatus in speech, developmental `stages' in cognition, etc. But these models are so different as to be almost incommensurable. They share only a point of view that cognitive objects, like categories and other `states of knowledge', are continuous and dynamic, rather than discrete and static. The notion of a `physical symbol' as a model for cognitive objects may be too narrow. Van Gelder and Port are editing a book of specially written studies to be published by MIT Press in his. The book explores these issues by bringing together both experimentalists and theoreticians.

Conference on dynamic representation in cognition.
Port and van Gelder

The conference was held November 14-17, 1991, Indiana Memorial Union, Bloomington, Indiana. An important idea seems to have emerged independently in many areas of cognitive research. This is the use of dynamic models for the representation of cognitive objects. Dynamic models have been proposed for such diverse cognitive phenomena as perceptual differentiation of scents, motor control of the limbs, linguistic control of the articulatory apparatus in speech,

developmental `stages' in cognition, etc. But these models are so different as to be almost incommensurable. They share only a point of view that cognitive objects, like categories and other 'states of knowledge', are continuous and dynamic, rather than discrete and static.

Our conference, held in November, 1991 was designed to facilitate the consolidation and unification of these various models with an eye toward their implications for the entire question of cognitive objects and models of cognitive activity. The notion of a `physical symbol' as a model for cognitive objects may be too narrow. This conference explored this set of issues by bringing together both experimentalists and theoreticians. The conference fostered a general understanding of dynamic models and both their limitations as well as their potential to explicate high-level cognitive phenomena.

Publications

Cummins, Fred and Robert Port (1993) On the treatment of time in recurrent neural networks. *Proceedings of the Connectionist Models Summer School, Paul Smolensky* (ed.) (L. Erlbaum Associates, Hillsdale NJ), pp. 211-218.

Cummins, Fred and Robert Port (1993) On the treatment of time in recurrent neural networks. *Proceedings of the Connectionist Models Summer School, Paul Smolensky* (ed.) (L. Erlbaum Associates, Hillsdale NJ), pp. 211-218.

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van Gelder, Timothy and Robert Port (1994) Beyond symbolic: Toward a Kama-Sutra of compositionality. In Vasant Honavar and Leonard Uhr (eds.) *Artificial Intelligence and Neural Networks: Steps Toward Principled Integration* (Academic Press), pp. 107-125.

Port, Robert, Fred Cummins and Devin McAuley. Naive time, temporal patterns and human audition. To appear in R. Port and Tim van Gelder (editors) *Mind as Motion: Explorations in the Dynamics of Cognition* (Bradford Books, MIT Press, in press 1995).

van Gelder, Tim and Robert Port. It's about time: Overview of the dynamical approach to cognition. To appear in R. Port and Tim van Gelder (editors) *Mind as Motion: Explorations in the Dynamics of Cognition* (Bradford Books, MIT Press) In press, 1995).

Port, Robert, Devin McAuley and Sven Anderson. Toward Simulated Audition in an Open Environment. To appear in E. Covey, H. Hawkins, T. McKenna and R. Port (editors) *Neural Representation of Temporal Patterns.* (Plenum Publishing, New York) In press, 1995.

Port, Robert and Tim van Gelder (editors) *Mind as Motion: Explorations in the Dynamics of Cognition* (Bradford Books, MIT Press, 1995)

Covey, Ellen, H. Hawkins, T. McKenna and R. Port (editors) *Neural Representation of Temporal Patterns.* (Plenum Publishing, New York, 1995)

VIII. Speech Research Laboratory

D.B. Pisoni

Ongoing research in the Speech Research Laboratory is concerned with a wide range of basic and applied problems in spoken language processing. All of these include research on speech analysis, synthesis and perception. Several recent projects have been concerned with spoken word recognition and lexical access as well as spoken language comprehension.

A long-standing research interest has been the development of evaluation and assessment techniques to study the perception of synthetic speech produced by rule. Studies of phoneme intelligibility, word recognition in sentences and comprehension are carried out to learn more about the differences in perception between natural speech and various kinds of synthetic speech produced automatically by rule using several text-to-speech systems. This work also involves studies designed to examine speech perception under high information load conditions, in order to learn more about how listeners allocate processing resources when the signals do not contain the redundancy of natural speech. Other studies are concerned with developing new methodologies to assess the real-time comprehension of fluent passages of connected synthetic speech produced by rule.

We have been working on a variety of issues related to variability in speech perception, particularly variability related to differences in speaking rate and differences among talkers. Our recent findings have shown that very detailed information about talker and rate variability is encoded into representation in long-term memory. These results raise a number of important issues about perceptual normalization in speech and the role of source characteristics in encoding and representation of phonetic information in memory.

Finally, we have a long-standing interest in perceptual learning, particularly as it might be applied to the reacquisition of non-native phonological distinctions. A major project has been concerned with the acquisition of English /r/ and /l/ by native speakers of Japanese.

The Speech Laboratory is well-equipped with extensive hardware and software for presenting complex acoustic signals to subjects and recording their responses in real-time. Three PDP-11/34 computers are used for perceptual experiments with human observers. There are also extensive computer resources for analyzing acoustic waveforms and generating experimental signals with a variety of speech synthesizers. In addition to the PDP-11/34 minicomputers, the lab currently has a dedicated DEC VAX-11/750 computer system and three DEC VAX work stations that serve as dedicated speech processing stations. The SRL VAX serves as the main computing facility for researchers in the Speech Lab. Each member of the laboratory has a CRT terminal at his/her desk. Additional graphics terminals are located throughout the lab and in several offices in the Psychology building. All computing facilities in the lab are interconnected using Ethernet. In addition, the Speech Lab VAX is interconnected to the campus computing system to facilitate transfer of files to colleagues in other laboratories, both on campus and at other institutions.

Detailed reports of research in the Speech Lab are not included here, in part because that work is more fully described in the annual progress report series entitled *Research on Speech Perception.* Institutions and individuals may obtain copies from the Administrative Assistant, Speech Research Laboratory, Department of Psychology, Indiana University, Bloomington, Indiana 47405. Research in the Speech Lab has been supported by grants from NIH and NSF and contracts from the U.S. Air Force Office of Scientific Research.

IX. Visiting Scientists in Human Factors:

1991:
Donald L. Fisher
Arthur D. Fisk

A. Seminars

Human factors seminar.

During the second semester (1991) we coordinated a topical seminar in applied experimentaUhuman factors. This seminar was attended by several faculty, students, and representatives from the industrial research community. The topics covered the spectrum of human factors including an overview of human factors issues and methods, training and skills development, speech perception, human computer interaction, communication product development, tactile perception, and forensics. In addition, four "outside" guests (i.e., not IU faculty) presented at the seminar. Leonard Matin from Columbia University discussed his work in vision; Eduardo Salas from Naval Training Systems Center (Orlando) discussed his work in team training and decision making under stress; F. Thomas Eggemeier from the University of Dayton discussed his applied work concerned with mental workload assessment; and Barry Lively from AT&T (Indianapolis) described the product development processes at AT&T.

Attention and human information processing seminar.

A weekly seminar (coordinated by Richard Shiffrin) was developed to discuss issues in attention, memory and visual search. The seminar was attended by several faculty and students from the Psychology Department. Gordon Logan from The University of Illinois and several of his students participated in an allay "attention fest." Based in part on discussions from this seminar several experiments were conducted (see below).

Face perception seminar.

Fisher also participated in a weekly seminar organized by Jim Townsend. The seminar explored various recent articles which developed more quantitative models of form and face perception. In addition, discussion centered on the mathematical developments required to make further progress in the area, including sections on tensor analysis and differential geometry. Participants included IU faculty from Departments of Mathematics and Psychology.

B. Research

Because of our involvement with the Institute and our discussions with faculty at Indiana University, several experiments were designed and conducted.

Transfer as a function of task structure.
Fisk

This experiment was designed to investigate the important issue related to what is learned in memory and in visual search. All manipulations were between subjects.There were three training conditions: 1) pure memory search; 2) pure visual search; and 3) hybrid memory/visual search. There were also the same three transfer conditions resulting in nine experiments groups: 1) train pure memory search transfer to pure memory search; 2) train pure memory search transfer to pure visual search; 3) train pure memory search transfer to hybrid search; 4) train pure visual transfer to pure visual; 5) train pure visual search transfer to pure memory search; 6) train pure visual search transfer to hybrid search; 7) train hybrid search transfer to pure memory search; 9) train hybrid search transfer to pure visual search. Results show that those subjects trained in pure memory search did not transfer well to tasks requiring visual search (either pure visual or hybrid memory/visual search). Subjects trained in visual search were capable of transferring, without deficit, to memory and hybrid memory/visual search. The data suggest different learning mechanisms in memory and in visual search.

Hybrid feature models of visual search.
Fisk

Fisher (among others) has shown that subjects cannot search a large number of display stimuli in parallel for a digit target in a background of letters when the display stimuli are each located roughly within a half degree of each other. Cohen has shown that subjects can search a large number of display stimuli in parallel for unique conjunction of form and color as long as the stimuli are spread relatively far apart. This suggests that the digit and letter stimuli might have been searched in parallel had fisher spread out the display far enough. The suggestion follows since the target is a unique conjunction of features when it is a digit just as is the target when it is a simple conjunction form and color.

As a test of the above hypothesis, subjects were asked to search for a target digh ("S") in a background of letters. Twenty frames were presented on each trial. The target appeared in exactly one of twenty frames on each trial. Subjects had to indicate the location (row and column) of the target. Three factors were varied across blocks: frame duration (40 or 80 ms), closeness (.5 or 1 degree between adjacent stimuli), and load (4 or 8 stimuli per frame). A very preliminary analysis of the results indicated that the difference between the performance of subjects in the high and low load conditions did not interact with distance. This suggests it may be difficult to use unique conjunctions of features to identify a target character in a completely automatic fashion when the features are defined either by their orientations or relative positions in space.

In order to better determine whether stimuli composed of features defined by their orientation could be searched automatically, we are now running a second and third experiment with stimuli much more simple than letters. In Experiment 2, the stimuli consist of two lines forming a 45 degree angle. The target consists of a unique conjunction of line orientations. In Experiment 3, the stimuli consist of two lines forming a 90 degree angle. The target does not consist of a unique conjunction of line orientations. We expect there to be an interaction of load with distance when the orientations are unique (Experiment 2j, but not when they are not unique (Experiment 3).

C. Other Efforts

Manuscript.

Many researchers interested in cognitive aging have argued that performance of older adults is simply a linear function of young adults. Further, they have argued that the old/young performance relationship is independent of task-specific cognitive requirements of the task. In a theoretical paper, we were able to demonstrate that this is not the case. We demonstrated that the scatter plot analyses used to argue for a general age-related slowing can hide the very task-specific age-related slowing they were designed to reveal. We demonstrated that the percentage of variance explained by such analysis can be both misleading and inappropriate. We showed reliable differences across tasks in the parameters relating younger to older adults' performance. We argue that the general, task-independent proportionate slowing which some cognitive aging researchers suggests explains so much of the variance in age-related performance is actually an average slowing which is a function of relatively small task-independent and relatively large task-dependent factors.

Because of our collaboration with the Institute, we developed a concept paper entitled "A formal theory of part-task training: Individualizing the learning and retention of high demand skills." This concept paper has been submitted and will be developed into a full proposal assuming interest fm the target agency.

Proposal — Morse Code.

Townsend and Fisher have together been asked to help the Army Research Institute further develop and quantify models of Morse code interception. The models require the derivation of closed form expressions for queueing networks with a finite number of customers, expressions which to date have been quite difficult to obtain. This work is now on a very small scale (currently, no experimental work is planned, at least at IU), but we hope that together with other members of the Institute the initial models might lead to a much larger project.

Support for editorship of Human Factors.

The Institute provided partial support for administration of Fisk's duties as Editor, Human Factors. This support is gratefully acknowledged.

1992: Andrew P. Dillon

1. Individual differences

An extensive literature review on the subject of individual differences in human information processing was carried out over the duration of the visit. This was coupled with regular meetings between Drs. Watson and Dillon to discuss the area and direct the review process. This work aimed at bridging the gap between traditional differential psychology and an emerging literature on individual differences in sensory and cognitive psychology, as well as identifying potential applications of this research in personnel selection in both military and commercial domains. A report outlining the findings of this review is in preparation, and will be presented for publication in due course.

Individual Differences, Human Information Processing and Personnel Selection
Abstract of Review Article by Andrew Dillon and C.S. Watson

The study of individual differences is as old as psychology itself, however most writers trace its historical roots to turn-of-the-century work on intelligence and ability testing by people such as Thorndike, Binet and Spearman. Almost one hundred years later it is clear that the domain of differential or correlational psychology has largely evolved separately from the experimental tradition so much so that writers as early as Boring (1929) and as recent as Jenkins (1989) refer regrettably to the two approaches as distinct disciplines within psychology, each concerned with different issues and employing different methods, often with little interaction between them.

Most noticeable is the difference in what Thorndike (1954) termed the "laboratory values" of these approaches. The differential approach is characterized by large sample sizes and the rigorous application of multivariate or factor-analytic techniques in the search for identifiable patterns of differences within the samples. For the differentialist, variations from the mean are thought to reflect latent mental structures or "factors" required to perform a task. The experimentalist however is less concerned with sample sizes and typically assumes relative homogeneity among subjects of whatever ability is required to perform a task, often relegating inter-subject differences into the category of error variance. Where individual differences are of interest, for the contemporary experimentalists at least, process (how a psychological event occurs) rather than structure (what psychological factors are employed) in task performance is its most important determinant.

The two disciplines can be bridged. Adams (1989) argues that the field of learning has always attempted to draw on the two approaches, if only as a result of the continuous debates about the relationship between intelligence and learning (see. e.g., Thorndike 1926, Gagne 1967). As will be shown, some investigators are beginning to take an interest in individual differences in human information processing and are applying differential concepts to experimental investigations (e.g., Dillon and Schmeck 1983, Sternberg 1985). Practically, such a marriage of correlational and experimental psychology has had demonstrated value for the selection of personnel in any number of situations. For example, as Overmier et al (1989) point out: the US Navy teaches over 7000 courses per annum to about 900 000 students. With failure rates for unselected samples often reaching 50%, any theory-based knowledge of the influence of instruction type on individuals of varying abilities becomes critically important. Similar arguments can be made for selection in a wide variety of industrial or commercial scenarios also.

Personnel-selection issues are likely to increase in importance in the future as technological developments change the nature of much routine work from predominantly physical to more cognitive activities. Coupled with rapid changes in technology, prediction of performance (and also the successful design of systems) must be based on the relation of human information processing abilities to work tasks and to the range of individual differences in these abilities.

This review examines the dominant themes of current differential psychology and discusses some of the efforts to apply an experimental approach to the study of individual differences in human cognitive abilities. It then examines the the previously attempted as well as the potential applications of this work to problems of personnel selection.

2. *Human Factors in the design of educational technology*

With members of the Department of Instructional Systems Technology (IST) and the Center for Media and Teaching Resources (CMTR) the question of usable technology in training and educational environments has been pursued through a series of regular meetings and workshops. Focusing on hypermedia applications, an attempt has been made to relate human factors approaches to system design (particularly models and techniques from the study of cognitive ergonomics and human-computer interaction) to instructional theory.

In particular, a group was formed by Dillon and members of CMTR to exchange literature and ideas on the similarities and differences between design and learning as viewed by psychologists working within the cognitive psychology paradigm with constructivist approaches to learning which are predicated on entirely different models of information and knowledge (i.e., they reject the idea of humans as information processors and emphasize the social and environmental nature of human learning and performance). This work had an impact on several ongoing design projects at CMTR and will be written up in a form suitable for publication.

With IST staff and students Dillon helped develop a prototype interface for a hypermedia system to train medical staff involved in the treatment of diabetes. This prototype formed the basis of a research grant proposal to NIH through the Diabetes Research and Training Center at IU School of Medicine (initial feedback suggests funding is likely). Dillon also contributed to the writing of a research proposal submitted to Eli Lilly and Co. by Dr. David Marrero of the School of Medicine.

With Dr. Thomas Duffy of the Dept. of IST, Dillon has pursued the problem of empirically distinguishing between human factors and constructivist approaches to technology design. These discussions are likely to lead to maintained contact and possible joint research on the design of usable systems.

3. Miscellaneous

Dillon was an invited speaker at the School of Library and Information Studies Workshop on Human Computer Interaction where he lectured on Human Factors in Information Usage and Design on May 24, 1992. In addition, occasional meetings between Drs. Shaw and Davis of SLIS and Dillon have led to the reformulation of a study of humanities scholars usage of library resources planned for this summer at IU.

Dillon was a member of, and named co-author of *ACPC Multimedia Application Area Plan*, a report from the University Planning Committee on multimedia in education, .

Dillon has been an advisor to the Financial Management Services group at IU on the development of a user interface for a new computerized financial management system for university use.

During his visit, Dillon has been working intermittently on *Designing Usable Electronic Documents*, a book to be published in 1993 by Taylor and Francis, London. The author is grateful for the time here that enabled aspects of this text to be developed and will duly acknowledge the Institute in the finished text.

1993: Gilbert Ricard

Summary

During Dr. Ricard's stay at Indiana University he reviewed human factors programs at a number of Universities, and catalogued academic programs that offer the Ph.D. degree in human factors. To these lists, viewpoints from a variety of sources have been added to characterize the field of human factors and the training of its specialists. This was done to convey the diversity of activities identified as human factors work as well as the variety of opinions about it. A good deal of that work benefits from an appreciation of several disciplines; however, many of the best practitioners of applied science have been trained in a single discipline (typically either experimental psychology or engineering). "Interdisciplinary training" should give students an appreciation of other disciplines but not necessarily attempt to endorse expertise in those fields.

Except for programs deliberately designed to communicate academic work to industrial needs (and support the resulting interest from industry), the institutions all have the sole purpose of engaging in contract work - mostly research and development. The list is probably not exhaustive. The work in human factors is performed by four types of organizations: government laboratories, groups within the engineering departments of an industry, contract research and development businesses, and the institutions listed. The institutions are basically competing in the same market as the contract research and development businesses. Their strong points are that their costs of doing business are lower (often they are not-for-profit or are subsidized), they are likely to have specialized equipment or talent which a business could not afford, and they often have some sort of charter for the work they do.

All of the institutions have provided materials. Some of the documents are for marketing and some contain proprietary information about charters or finances. All of this material is on file at the office of the Institute for the Study of Human Capabilities.

At the time this review was being completed, the directional attention of the Institute was shifting from the broader area of human factors to human/computer interaction. Although this changes the organization's interest in specific institutions, it should have little effect on the section containing suggestions. They remain the same.

Human Factors Institutes

Aviation Research Laboratory
University of Illinois
Champaign, IL

Center for the Application of Human Factors in Aviation
University of Central Florida and Embry-Riddle University
Daytona, FL

Center for Ergonomics
University of Michigan
Ann Arbor, MI

Institute for Cognitive & Decision Sciences
Straub Hall
University of Oregon
Eugene, OR

Institute of Safety and Systems Management
University of Southern California
Los Angeles, CA

Institute for Simulation and Training
University of Central Florida
Orlando, FL

Management Systems Laboratories
Department of Industrial and Systems Engineering
Virginia Polytechnic Institute and State University
Blacksburg, VA

University of Dayton Research Institute
University of Dayton
Dayton, OH

University of Michigan Traffic Research Institute
University of Michigan
Ann Arbor, MI

UNC Highway Safety Research Center
University of North Carolina
Chapel Hill, NC

Center for Technology Transfer
University of Pennsylvania
Philadelphia, PA

COSMIC
Computer Services Annex
(NASA-affiliated)
The University of Georgia
Athens, GA

Industrial Liaison Program
Massachusetts Institute of Technology
Cambridge, MA

Office of Technology Licensing
Stanford University
Palo Alto, CA

Ways the Institutes Differ

1. Relation to Universities

The institutes listed above differ along a number of dimensions, and it is worth discussing some of them. One way they differ is the degree to which they are operated by personnel of a university and controlled by policies of that university. Some of the institutes, such as the Center for Ergonomics at the University of Michigan or the Institute for Cognitive & Decision Sciences at the University of Oregon are wholly "owned" by (or evolved from) an academic department within a university. Their purpose is to accept projects and funds, employ people to do the work, and in general act as a manager for the work the institute does. Members of these institutes are faculty scientists who propose and then take responsibility for the performance of projects that are done in their laboratories typically by graduate students.

At the other end of this continuum are groups that are only loosely attached to a university and their purposes are usually closer to those of business. They may be like MIT's Industrial Liaison Program which acts as a marketing organization for the skills and products of the faculty, or they may be like COSMIC which distributes (under contract) software developed with tax money at the various NASA research centers. NASA's Ames Research Center, by the way, has appointed various places a "Center for Excellence in (space or aeronautics). Usually these are one individual's laboratory, and the designation is to make it easy to fund them directly, but it appears that they act much as independent grantees. Typically though, these more peripheral arrangements perform services for the university. Here also are included the various technology transfer offices that license patented material, try to support small businesses based on university work, and manage consulting arrangements.

Between these extremes are the rest of the group. Some are like Management Systems Laboratories (sheltered by the university and engaging in business), some are like the Institute for Simulation and Training where the staff are wholly employed by the institute, and some are like the Institute for safety and Management Systems where the institute provides courses and degree programs aimed at a particular sector of industry.

Last, mentioned as a separate case is the University of Oregon's Institute for Cognitive and Decision Sciences, which is a member of a consortium of similar groups funded by the McDonnell Foundation. All of the member groups are "academic" institutes so they are closely attached to their universities, but there is strength in numbers and it appears that the advantage such an arrangement has is the internal bargaining power afforded by long-term reliable funding.

2. Relation to Industry

The institutes differ also in the relation of their work to industry. Some of the groups were started at the specific request of a member of an industry, a state government, or a Department of Defense group, but most were not. Usually, it was the interest of a single individual, but regardless of how they were started, the real point of comparison here is the degree the work of the institute is aimed at a specific source of funding. Probably the best example is the Aviation Research Laboratory at the University of Illinois where the equipment and staff were chosen to build the capability of performing aviation human engineering work. The presence of a state and national industry has

provided careers for the graduates and there are many sources for funding (such as the DoD, DoT, FAA, and NASA) that have contributed problems and resources. The Institute for Cognitive & Decision Sciences fits this model (in a backwards sense) - their research fitted the goals of the funding organizations and so made a good match. The institutes at the University of Michigan (the Center for Ergonomics and the Traffic Research Institute) were also created for specific markets. The ergonomics group was basically started by the Ford Company and the traffic research group has long been funded by the Department of Transportation.

At the other end of this dimension are groups like the Institute for Simulation and Training and the University of Dayton Research Institute. Both of these were started to cater to a specific customer, but within the mission of that organization, the institutes' work is fairly general. UDRI does physical science and engineering as well as supplies on-site skilled employees to government laboratories and the IST has projects on computer science as well as training methods.

All of these groups have the potential of providing a fairly broad range of "services" depending on the skills of people at the various universities, apparently no group explicitly does this. Probably this is just because they have all followed the path of least resistance and have done whatever work seemed to be in demand. While it is certainly easier to market work geared to a customer's needs (especially when the customer is in the business of sponsoring just that sort of work), the original goal in forming Indiana's human capabilities institute was to interest a major research university in applied work, and the need for that still exists. The marketing problems are those of finding the people who need the work, finding them at the right time, and building a record of successful projects. The ideal solution is to have the market come to Indiana's institute, knowing its capability and confident that it can provide a solution in the form that is needed. This happy state, though, would require patience and an investment on the part of the university. Those institutes that have survived and have become relatively permanent parts of their institutions have done so because they met needs both within and external to the university and they generated funding for work that was compatible with the preferences of its members.

3. Mechanisms for Visibility

Almost all of the groups surveyed used a variety of mechanisms to get visibility for work done, but which also advertised the potential for similar work for the future. One of the most common tools is the brochure. Typically these are at least four-color prints on stiff glossy paper, often they are some sort of multiple-page fold-out arrangement, and occasionally they contain inserts. Some used a magazine format - much like a yearly stockholder's report - but all had photographs to illustrate products, capabilities, or the people doing the work. MIT's Industry Liaison Program uses an informal tone for the text in its somewhat monthly newsletter partly to reduce the apprehension people in industry might have for contacting well-known researchers. These brochures are given to those who request information about the institutes, but a typical use of such material is to rent a booth at a conference and give them away. Usually, the glossy packets are expensive and are used for potential customers, but an inexpensive handout is the format used on its "cheat sheets" by Indiana University's computing center - 8 1/2" by 14" stock fan-folded to be pocket size. Always, the attempt is to get a name and telephone number to someone who actually may be interested.

Another obvious method for visibility is the word-of-mouth advertising that comes from a flow of visitors to the group and from graduates who inform employers about work the group can do.

These methods are slow and unreliable, but in the long run, they are important ways to disseminate information.

Papers and contracted reports are often distributed to a list of people who may be interested in the work or who are sponsors of similar work. In the government, this is the way technical reports are distributed, and one of these lists is the Office of Naval Research's distribution list for the cognitive research they sponsor. Many groups have newsletters or lists of papers and reports they will provide also. All of this attempts to get information into the hands of those that want it, but it is a useful form of advertising.

Another tool for visibility is the yearly meeting. Usually these take the form of project reviews for sponsors or a meeting on a topic, such as human error. A useful role for a meeting, though, is its way of advertising that a group performs certain work, and like the distribution lists for technical reports, the trick is to get the right people to come.

Last, as institutes become large and have commercial business, employing an individual to be a marketeer is a strategy that is useful. The work is tracking sources of funding, getting information about potential customers, making sales presentations, and in general, acting as an "interface" between the technical members of the group and the commercial world. Large businesses who do contract work for the government typically employ such people because the information and analyses they provide keeps the business competitive.

4. Economic Dependency on the University

In this dimension information is sparse. The only datum available here is that the Institute for Cognitive & Decision Sciences at the University of Oregon receives $20,000 per year from the university to fund a part-time secretary and travel costs for visitors. The rest of their funding, about $300,000 per year, comes from the two foundations. It appears that the more "focused" institutes (such as the Institute for Simulation and Training or the Aviation Research Laboratory) have larger incomes and depend very little on university funds. Management Systems Laboratories at Virginia Polytechnic Institute and State University has the agreement that the university's general fund pays salaries during periods of insufficient work, but the institute was built with a $1 M per year contract from the U. S. Department of Transportation so they have not had to depend on the university. This seems to be true of most groups. If they had to depend on their university, they probably would not exist.

5. Types of Services Offered

The services institutes have offered range from basic research to consulting and acting as "body shops" to provide skilled personnel under contract. Typically, most do applied research as they are funded to do, but certainly basic research is represented. The cognitive and decision sciences institute at Oregon does basic research and apparently institutions such as MIT do a lot of basic work that is funded or sponsored by an industrial client. Certainly their Industrial Liaison Program has been a success. The Oregon institute is the closest to the group here at IU in the work they do and the interests of the members.

Groups flourish that fill a need in the market place. In this case, institutes exist because they perform a service that is needed. When the service is clearly related to a market, then it is easy to

see how the institute sustains itself. Thus, most of these institutes have a "focus" or specialty - it could be aviation, automobile design, simulation and training, or whatever - that reflects their intended market. They in turn are supported by work in that marketplace. One role of a common theme for these groups is the internal cohesion it provides. It gives the group its reason for being, but it also is the selling point for the world external to the university. Along with providing graduates practical experience and making the "marketing" of the work easier, having a cohesive topic for the work of an institute also allows the more informal word-of-mouth communication to be more efficient. Graduates become employed by an industry, tell others of work at the institute, encourage them to take their problems to the institute, and so on.

The Indiana University Model

The Institute for the Study of Human Capabilities started as part of an Air Force Office of Scientific Research program to encourage the faculty at a major research university to take an interest in applied problems. The institute sponsored several meetings, has supported a number of visitors, and has sponsored some applied projects by its members. The world has changed a bit since the time of the initial funding, but there is good reason to continue and possibly try to expand the original goal of the organization. The Department of Defense as well as the traditional grant institutions have had their budgets reduced, and the prospect for relative increases of these budgets seems slim for the rest of the decade. Interest in applied research, then, represents a means of supplementing the traditional sources of funding for research that are strained to support even a proportion of the worthwhile proposals they receive.

The vision for the Institute is to use skilled faculty to solve real-world problems that fit the various interests of individuals. This is in keeping with the University's basic mission of research and teaching; it only broadens the base of the source of problems and funding, but it serves several goals. First, inviting applied work is a means of obtaining additional support during times of reduced government spending on science and education. Second, acquainting faculty and graduate students with applied problems historically has been a stimulus for further basic research. One only has to reflect on the effect each of the world wars has had on the development of Psychology to see that solving real problems quickly defines the technology produced by a science. Last, during this period of slow growth, experience at applied research broadens the employment prospects of recent graduates - increasing the likelihood they will be able to continue the science in which they were trained. The institute with its current members can provide competence in four areas: 1.) cognition and decision-making, 2.) sensation and perception (audition, speech and hearing, vision, skin senses, and language), 3). mathematical modeling, and 4.) computer science. There has been some interest in using human/computer interaction as a topic of concern for a variety of groups on the Indiana campus, so that in addition to the topics mentioned, the institute could unite interests from the Education, Mathematics, Philosophy (logic), Language, Computer Science, and Psychology departments. Either way, the group could provide interdisciplinary work to customers and experience to graduate students.

Such a group could seek work from industry and government laboratories as well as from those who already contract with these groups. That is, the institute can vie for contracts or could sub-contract work in its specialties.

Appendix A

Human Factors Courses, Programs, and Training

There are three documents that are helpful in determining what various graduate programs in human factors are like, and what they possibly should be like. The Human Factors and Ergonomics Society publishes two of them. One is the *Directory of Human Factors Graduate Programs in the United States and Canada,* which lists descriptions of departments that offer human factors training, their admission requirements, some of the course offerings, and a list of the faculty. The other is a set of guidelines the Society uses to evaluate graduate programs in human factors. It is the *Human Factors Society Accreditation Self-Study Report Guide* of 1990, and it gives what some feel is current adequate preparation for the discipline (at least broadly defined). The third document is a 1992 report by the Human Factors Committee of the National Research Council entitled *Human Factors Specialists' Education and Utilization: Results of a Survey.* It provides the results of a National Research Council study comparing human factors practitioners' training and daily work activities. These three documents are also deposited at the Institute for the Study of Human Capabilities at the Poplars Research and Conference Center.

The lists below are from descriptions (from the *Human Factors Society* Directory) of PhD programs in Human Factors that mentioned required or elective courses. Not all of them did so the list is best taken to illustrate the variety of topics that are put together as Human Factors. The lists do not differentiate whether or not it was an engineering or psychology program that offered the course.

Required Courses

1. Courses Having an Engineering Flavor
- Research Methods in Engineering Psychology
- Human Performance in Systems
- Engineering Psychology
- Human Factors in Systems Design
- Displays and Controls

2. Experimental /Cognitive/Physiological
- Cognitive Bases of Behavior
- Physiological Psychology
- Human Performance
- Learning and Memory
- Sensation and Perception
- Applied Experimental Psychology

3. Social/Personality/Industrial
- Social Psychology
- Organizational Psychology and Personnel Selection
- Ergonomics
- Environmental Psychology
- Individual Differences

4. General

History and Systems
Foundations of (or Introduction to) Human Factors
Research Methods
Quasi and Non-Experimental Methods
Human Factors Research Methods
Statistics - usually 2 or more courses - through multivariate analyses

The main point is that the "Core" of almost the entire profession is training as an experimentalist. Different programs, depending largely on the interests of their faculty, emphasize the different groups of courses differently, but certainly most programs required courses from group 2 and quantitative methods courses from Group 4. The only exceptions seemed to be engineering programs specifically aimed at training practitioners for design work or programs with an emphasis on health and safety. The topics that human factors specialists consider change so rapidly that training on any one is of little value. They are far better prepared by knowledge of measurement and experimentation, the facts of current experimental psychology, and an understanding of how to define and choose problems for work.

Electives

1. Cognitive/Computer Related

Human-Computer Interaction
Applied Human Information Processing
Mental Models
Cognitive Engineering
Artificial Intelligence
Attention and Information Processing

2. Applied Experimental

Psychophysics and Scaling
Spatially Coordinated Behavior
Skilled Performance
Visual Perception
Audition and the Effects of Noise
Human Memory
Software Psychology
Judgement Processes and Decision Research
Mathematical Models of Measurement

3. Engineering/Systems Design

Aviation Psych
Display Design
Complex Systems
Simulation and Training Systems
Operations Research
Simulation and Modeling Techniques
Human Error
Biomechanics
Task Analysis

4. Personnel/Social/Environmental Factors

Personnel and Training Systems
Work and Job Design
Environmental Design
Social and Environmental Factors in System Design
Managing Technical Innovation
Industrial and Organizational Psychology
Multivariate Statistics

Here the grouping was a bit more arbitrary and my divisions tended to reflect how topics are related currently in the field. Some of these courses, such as "Models of Measurement", seem to be extensions of a core, while others, such as "Task Analysis," are difficult to imagine as courses. Others, such as "Display Design" represent topics that have economic impact and which are becoming "academicized" as principles governing layout and content are abstracted and tested. The diversity of topics both shows the varied interests of teaching faculty and the nature of the discipline. Lots of topics seem to fit between the interests of psychology and engineering. Duplication of courses on this list with the previous one merely indicates that one program's requirements were another's electives.

Below are listed the 65 schools that offer a PhD in Human Factors. They are divided into those that offer the degree in an engineering department and those that offer it through a psychology department. Typically the engineering programs stress safety, work analysis, and system design, and the psychology departments treat human factors as applied psychology. The (*) indicates that there is an additional department at the school (typically it was either engineering or psychology) that offers a degree in Human Factors.

Engineering Programs (35)

Auburn University
Iowa State University
Kansas State University*
Louisiana State University
New York University
North Carolina State University
Northeastern University
Ohio State University
Pennsylvania State University
Purdue University
State University of New York at Buffalo
Technical University of Nova Scotia
Texas A & M University
Texas Tech University
University of California at Los Angeles
University of Cincinnati
University of Connecticut
University of Illinois
University of Iowa
University of Louisville
University of Lowell
University of Massachusetts

University of Miami
University of Michigan
University of Nebraska-Lincoln
University Pennsylvania
University Southern California
University of Texas at Arlington
University of Toronto
University of Utah
University of Washington
University of Waterloo
University of Wisconsin-Madison
Virginia Polytechnic Institute and State University
West Virginia University
Wichita State University

Psychology Programs (24)

Catholic University
George Mason University
Georgia Institute of Technology
Kansas State University*
Miami University
New Mexico State University
Ohio State University*
Old Dominion University
Pennsylvania State University*
Rice University
Stevens Institute of Technology
Texas Tech University*
University of Central Florida
University of Cincinnati*
University of Connecticut
University of Illinois*
University of Iowa*
University of Louisville*
University of Maryland
University South Dakota
University Southern California*
Virginia Polytechnic and State University*
Wichita State University*
York University

A Program

Appendix A of the HF&E Society's accreditation report guide provides a nice quote to define human factors specialists and their training. "Human Factors is concerned with the application of what we know about people, their abilities, characteristics, and limitations to the design of equipment they use, environments in which they function, and jobs they perform." Thus a program to train practitioners "should contain knowledge about the properties of people, research methodologies,

analysis and design methodologies, and some basic skills in mathematics, computers, writing, and speaking. It should contain practical experience in defining and solving human factors problems. Finally, it should include research experience." From this point-of-view, the Human Factors and Ergonomics Society suggests that a training program address these six topics.

1. **Knowledge about properties of people**
   Of the various ways to divide information about human abilities and actions, two merit emphasis in a training program: one is to emphasize the human being as a processor of information and the other is to regard him as a physical engine (a source of action).

2. **Research Methodologies**
   This is the standard set of skills about formulating problems, designing studies and analyzing them.

3. **Analysis and Design Methodologies**
   Here the emphasis is on techniques such as mission and task analysis, function allocation, and the art of trading safety, cost, operator workload, and performance that goes into system design.

4. **Skills**
   In addition to an emphasis on written, verbal, and mathematical communication skills, Human Factors specialists should have some level of familiarity with computers.

5. **Research Experience**
   The Society and most practitioners feel that competence at research is paramount. The discipline is new enough that practitioners will always be reading research and many will be employed to perform it. Either way, more than a casual acquaintance with research is desirable.

6. **Practical Experience**
   Human Factors is an applied field so that practice at identifying and defining problems is as much a part as the skills to solve them. Appendix C of the HF&E Society's accreditation document lists a number of the means developed to involve students with real problems.

The above six factors were mentioned by Fisk and Fisher in their paper on *The Development of a Human Factors Program at Indiana University,* but they are listed here again as some (such as #3 and #6) are difficult to provide in an academic program. This is probably the best reason that programs such as the ones at the University of Illinois have been so influential - there is a lot of on-going contracted work with which students can become involved and it all deals with problems of one applied area - aviation - that is a large national enterprise that can employ them. A good portion of the people in the aviation human factors field have come from the University of Illinois - probably for several reasons. One is the focus of both the engineering and psychology Human Factors programs on aviation. The "critical mass" of people and equipment has made it easy to attract funding. Another is the availability of each program to students in the other - psychology students can learn about engineering techniques and approaches in real settings - an appreciation that employers value. Last, (and this is one of the strengths of Indiana University) Illinois is a major university that attracts bright students who probably will succeed in whatever situation they find themselves. The existence

of a contract-supported laboratory tends to make students aware of funding and who does it (and how to get it), and after a while, the reputation of the place makes it easy for students and employers to find each other.

Last, the National Research Council was requested by the Army Research Institute to examine human factors practitioners' work and training and make determinations of the requirements for such people in the future. The resulting telephone survey sampled people obtained from the membership lists of a variety of organizations, and survey was limited to those the felt that they were doing human factors work. The sample was not limited to members of the Human Factors and Ergonomics Society, for instance, so the work included as "human factors" was broadly defined. In addition, the data were divided according to whether the respondent was a working specialist or supervisor.

The report drew two conclusions and made several recommendations, some of which might be helpful here. First, they found that the majority of people worked in six areas: computers, aerospace, industrial processes, health and safety, communications, and transportation, and that they were a diverse group. Many considered themselves part of a traditional profession, such as psychology or engineering, and only about 40% identified with Human Factors as a profession. The NRC's point was that a variety of skills are employed in human factors work and that this posed a problem for the standardization of training. The other side is that a particular program may view itself as training people for only part of the human factors profession. Second, the study found that supervisors felt that they were poorly prepared for supervisory responsibilities and that new graduates, in general, were ignorant of the "business" side of the discipline. In addition to ignorance of the mechanics of doing business, recent graduates were well schooled in theory and research but they were not prepared for the evaluation studies required in the workplace.

The NRC report lists six recommendations. They are:

1. Training for the profession should be interdisciplinary. System integration requires extensive communication across disciplines so that both engineering and psychological issues are addressed knowledgeably, and the NRC recommends that training programs provide cross-discipline experience, one way or another, to foster the understanding and appreciation required by such work.

2. Use a core curriculum. This recommendation was made because of the diversity of skills and backgrounds that appear in the profession, where a set of elective courses can keep the core responsive to the needs of employers, and a curriculum built about a set of required courses supplemented by electives is one way to do this. A glance at the required and elective courses taken from the directory of graduate programs in human factors shows that across most programs, this has been the path chosen. Some schools had no requirements, but most required some courses in psychological theory and research as basic to a program. I'm sure Indiana University would be comfortable with that approach. A senior-level or first-year graduate course could cover the basics and a flexible set of seminars would address particular topics of interest.

3. Develop and encourage internship arrangements. This recommendation was to solve two problems: first, that students often did not have much understanding of how real-world organizations addressed problems, and second, that their dissertations were often far removed from practical applications. This also is the main task for the Institute - to bridge the gap

between the problems of industry and government and the capability represented by IU faculty and students. To date, the most successful of such "bridges" have had a subject of mutual interest where the university developed particular capabilities that enabled it to become noted as a center for particular work. In human factors, this approach has been to develop expertise in one of the six areas listed in the NRC's first conclusion. Examples are the Aviation Research Laboratory at the University of Illinois and the Traffic Research Institute at the University of Michigan. Both of these have received funding from both industry and the appropriate government organizations.

Aside from questions of focus and funding, a separate issue is the mechanics of operating internship arrangements at IU where it seems there are not many sponsors nearby. Students work on a dissertation, for instance, away from the university, often find themselves caught between the political or funding limitations of the sponsoring organization and the values of the university.

4. Support Training. Another of the NRC's recommendations is related to #3 but was aimed at sponsoring activities. This was to create graduate traineeships in human factors. The emphasis here is to encourage an interdisciplinary view of the field and of development work. Typically, graduate programs have poorly bridged the gap between theory-based work and systems integration. More and more, good design reflects well-integrated systems, not the application of a particular discipline.

5. Extend human factors to new areas. The main reason the "human factors" point-of-view has remained popular is that it produces better systems or products. Most of its practitioners, though, have remained in the six areas mentioned earlier where the cost of products or system failures is high or where a large market exists for particularly easy-to-use products. The aviation and computer industries obviously fit these criteria. International competitiveness will eventually force other industries to make their designs more user-centered and the NRC felt that universities could prepare people for an expanded market their skills.

In addition to these recommendations there were several others about encouraging women and minorities into the field, continuing the running evaluation of the field of which the NRC study was part, and providing supervisory training to graduate students. This last comment was made in response to human factors supervisors' comments that they and the people they supervise were poorly prepared for management responsibility.

6. Provide supervisory training. This recommendation was in response to the comments of supervisory people who felt management training should have been part of their schooling. It seems that recently many graduates from human factors programs are employed by small businesses that do not provide training when an individual is asked to supervise others. Large ones do, and there is an industry that provides training courses on management and supervision. This recommendation may be surprising, but the human factors profession does have a strong business flavor and universities, typically, have not been places where students learn to mix the values of a profession with those of business.

These recommendations may just reflect the times, or perhaps what particular members of the NRC's study committee wished to emphasize. Either way, a human factors training program at Indiana University should be aware of these issues and, at least, have taken them into account.

"Human Error" Conferences

One of the most successful activities of the Institute has been its sponsorship of three "Human Error Conferences." These conferences were each two days in duration, and were held on the Bloomington campus of Indiana University. Each of them included several nationally known visiting speakers whose work represented an integration of basic and applied research, in the general area of human factors. Several of the Institute's scientists also presented papers at each of these conferences, describing basic research with clear relevance to applied issues in that same field. The co-chairman of each of the conferences was one of the visitors, whose role was to participate in the selection of the other visitors, while the local co-chair (C. S. Watson) was responsible for the overall conference arrangements. The conferences were well-attended both by local scientists and by contingents from Wright-Patterson AFB, as well as elsewhere in the U.S. (Conference programs available on request.)

Human Error Conference No. 1, March 21-23, 1990

Visiting Speakers:

Christopher Wickens (co-chair)	Univ. of Illinois
Hershel Leibowitz	Univ. of Pennsylvania
David Woods	Ohio State University
Susan Dumais	Bell Laboratories
Peter Hancock	Univ. of Minnesota

Human Error Conference No. 2, March 20-22, 1991

John Swets (co-chair)	Bolt, Beranek and Newman, Inc.
Robert Sorkin	Univ. of Florida
Susan Dumais	Bell Laboratories
Arthur Fisk	Georgia Tech. Univ.
Donald Fisher	Univ. Massachusetts
Phillip Ackerman	Univ. of Minnesota

Human Error Conference No. 3, March 25-27, 1992

Neville Moray (co-chair)	Univ. of Illinois
Raja Parasuranam	Catholic Univ.
James Reason	Univ. of Manchester,UK
Earl Hunt	Univ. of Washington
Barry Kantowitz	Battelle Res. Center
Colin Drury	SUNY at Buffalo, NY
Andrew Dillon	Loughborough Univ.,UK

Other Sources of Support

Auditory Research

NIH R44-DC00893 (SBIR Phase II) 1/1/92 - 12/31/93	Indiana Speech Training Aid: Stage IV D. Kewley-Port, Communication Disorders Technology, Inc. - $500,000
NIH 4/1/91 - 3/31/96	Dynamic Attending and the Perception of Patterns in Time G.R. Kidd - $321,317
ONR 12/1/90 - 11/30/93	Models for Continuous Auditory Processing R. Port - $322,390
N.I.H., (Investigator) 1/94 - 6/94	Second Language Intelligibility Trainer D. Kewley-Port, Communications Disorders Technology, Inc. (S.B.I.R., Phase I) - $74,938
NIH R29-DC00545 4/1/91 - 3/31/96	Dynamic Attending and the Perception of Patterns in Time G. Kidd - $321,317
AFOSR F4962092-J0506 DE 8/1/92 - 7/31/95	Title: The Perception of Complex Auditory Patterns C. Watson, G. Kidd, D. Robinson - $247,188
NIH R01 DC00250-10 7/1/94 - 6/30/98	Title: Discrimination and Identification of Auditory Patterns. C. Watson, G. Kidd, D. Robinson, D. Kewley-Port - $440,194

Vision Research

NSF 2/1/91 - 1/31/94	Physical Constraints on Form: Investigating Visual Information for Event Recognition and the Judgement of Sizes G. Bingham - $175,000
I.U. Dean of Faculties Ventures Fund Award 4/3/92 - 4/3/93	A Study Group on Dynamical Systems Multidisciplinary in Cognitive Sciences Bingham, Port, van Gelder, and Thelen - $2,500
Grant-in-Aid of Research, Indiana University, awarded on August 26, 1992	Visually Guided Reaching Research $500
NIH (NEI) 5R01EY05109 4/1/93 - 3/31/96	Optical and Retinal Limits to Human Visual Performance L Thibos - $676,290

Cognition and Decision Making Research

NSF BNS 911281 8/1/91 - 1/31/94	Stochastic Theory, Method and Experimental Design in the Identification of Mental Architecture James T. Townsend - $249,913
NIH R01 DC00095-22 7/1/86 - 6/30/93	Cutaneous Pattern Perception J. C. Craig - $997,361
NIH R01 DC01577 7/1/92 - 6/30/95	Haptic Perception of Multidimensional Patterns J. C. Craig - $72,952 (Subcontract with Gallaudet University)
NIH PHS NIDCD DC00-111-16 3/1/88 - 2/28/95	Speech Perception and Spoken Word Recognition D. B. Pisoni - $1,637,392 (Total direct costs)
AFOSR 870079 1986 - 1993	Institute for the Study of Human Cognition R. Shiffrin - $1,505,000
NIMH PHS Merit Award 12727 1991 - 2001	Information Processing and Retrieval R. Shiffrin - $1,110,000
NIH TR-MH19879-01 1993 - 1998	Training Grant R. Shiffrin - $940,417
NSF Graduate Research Training Grant 1993 - 1998	Modeling Human Cognition R. Shiffrin - 1,100,000
Indiana University 1980-	Luther Dana Waterman Research Award R. Shiffrin - $13,000

Bioacoustic Research

NIH 1 RO1 NS29467-01 5/1/91 - 4/30/94	Motor Control in Production and Development of Birdsong R. Suthers - $87,930 (Direct costs - Yr. 1)

Connectionism

NSF BBS 1992 - 1994	A Connectionist Model of the Development of Similarity M. Gasser, L. Smith - $173,125
NSF Young Investigator 1992 - 1997	M. Gasser - $125,000
ONR N0001491J-1261 12/1/1990 - 11/30/1993	Models for Continuous Processing of Auditory Signals R. Port - $460,000

NSF 92-04046
8/1992 - 8/1993

Noise and Tone: A Study in Cognitive Ethnomusicology
R. Port, with C. Fales - $23,045

ONR N0001491J-1261
12/1/90 - 11/30/93

Models for Continuous Processing of Auditory Signals
Port - $460,000

ONR
3/15/93 - 9/15/93

Conference on Neural Representation of Temporal Information
Ellen Covey and R. Port - $16,687

NIMH
7/1993 - 6/1998

Mathematical Modelling in Experimental Psychology
Shiffrin, Port, Castellan, Townsend - $237,378

Extramural Activities

C. S. Watson is the director of the Institute for the Study of Human Capabilities and serves as an advisor to the National Research Council's Committee on Hearing, Bioacoustics and Biomechanics (CHABA). He recently served as chairman of CHABA Working Group 95, on Personal Speech Perception Aids for the Hearing Impaired. He is also a member of ASA Standards Committees S3-63 on Acoustical Warning Devices, and S3-76 on Computerized Audiometry. Watson serves as a reviewer for the *Journal of the Acoustical Society of America, Journal of Speech and Hearing Research, and Perception and Psychophysics.*

R. M. Shiffrin serves as the associate director of the Institute for the Study of Human Capabilities. He is the first director of the Indiana University Cognitive Science program and serves on the National Science Foundation review panel for Cognition and Perception. He is consulting editor for *Acta Psychologia, Memory & Cognition, Psychological Review, and Journal of Mathematical Psychology.*

G. P. Bingham is a consulting editor for *Ecological Psychology,* and an associate for *Behavioral and Brain Sciences.* He serves as a referee for the *Journal of Experimental Psychology: Human Perception and Performance; Journal of Motor Behavior; Ecological Psychology; Behavioral Research Methods, Instruments, and Computers; Human Movement Science and for the National Science Foundation, division of Neural and Behavioral Sciences, Program in Language, Cognition, and Social Behavior; Human Factors; Memory and Cognition; Developmental Psychobiology, North American Society for the Psychology of Sport and Physical Activity.* He is a member of the Psychonomic Society, Sigma Xi, the International Society for Ecological Psychology, and the American Psychological Society.

A. Bradley serves as editorial reviewer for the *Journal of Neurophysiology, American Journal of Optometry and Physiological Optics, Vision Research, Journal of the Optical Society of America, Clinical Vision Research, Investigative Opthalmology and Visual Science, Ophthalmic and Physiological Optics, Gordon Heath Symposium Papers, Butterworths Scientific Publishers, Optometry and Vision Science, Behavior Research Methods, Instruments, & Computers, Developmental Psychobiology.* He also serves as special Feature Editor for *Optometry and Vision Science* (Simultaneous bifocal and multifocal vision). He is a grant reviewer for National Science Foundation and NIH. He was recently appointed to the editorial group of the "Dictionary of Visual Science" and served as 1992 General Chair of the Optical Society of America topical meeting: Non-invasive Assessment of the Visual System. He was awarded the Glen Fry Award for Visual Science by the American Academy of Optometry in December, 1991; he received the Best Paper Award for 1991 by the Society for Information Display. He is consultant to the FDA on tests of visual performance. He is currently writing a book for Optometry students studying for their National Board Exams.

N. J. Castellan, Jr. is the editor of *Behavior Research Methods, Instruments, and Computers and Judgment/Decision Making,* a newsletter. He serves on the editorial boards of *Organizational Behavior and Human Decision Processes, Behavioral Decision Making, Social Science Computer Review, and Interactive Learning International* . He is chair of the Forum on Research Management, one of three standing committees of the Federation of Behavioral, Psychological and Cognitive Sciences. Professor Castellan died in December, 1993. As noted earlier, this report is dedicated to him.

J. C. Craig served a four-year tenure as Associate Director of the Institute for the Study of Human Capabilities (1988 - 1992). He serves as a member of special review panels of NSF, NIH, and SBIR as well as having been a member of the NIH Study Section on Sensory Disorders and Language. He recently served on the Task Force for updating the National Strategic Research Plan for the National Institute on Deafness and Other Communication Disorders. He is the recipient of the NIH's Javits Neuroscience Investigator Award, July 1986 to June 1990, and the Claude Pepper Award from July 1990 to June 1993.

M. Gasser served as co-organizer of Midwest Connectfest, a meeting of connectionist researchers in the Midwest. He is a member of AAAI, Association for Computational Linguistics, ACM, Cognitive Science Society, Midwest AI and Cognitive Science Society, Linguistic Society of America, and International Neural Network Society. He has served on the review panel of *Neural Information Processing Systems, Psychological Review, Studies in Second Language Acquisition, Behavioral and Brain Sciences, Cognitive Science, Psychological Review, Computational Linguistics, and Machine Learning.*

S. L. Guth is an ad hoc member of the U.S. Committee of the International Commission on Illumination and a Fellow of the Optical Society of America. He is a referee for grant proposals submitted to NIH and NSF as well as a referee for articles submitted to *Journal of the Optical Society of America, Vision Research, Psychological Review, Journal of Experimental Psychology, Perception, Journal of Color Research and Application, Perception & Psychophysics, and Science.* Dr. Guth has a strong affiliation with the vision group at the Laboratory of Applied Physics of the French Center for Scientific Research in Paris, where he maintains collaboration with Hans Brettel and Francoise Vienot on research that is related to his color perception and visual adaptation model.

D. Kewley-Port referees grant proposals for NSF and has served as a member of several NIH review panels. She reviews manuscripts for *The Journal of the Acoustical Society of America, The Journal of Speech and Hearing Research, IEEE Transactions on Acoustic, Speech and Signal Processing,* and *Computer Users in Speech and Hearing.*

G. Kidd is a member of the American Psychological Society, the Acoustical Society of America, the International Society for Ecological Psychology, and an associate member of the Psychonomic Society. He has reviewed manuscripts for *Journal of Experimental Psychology: Human Perception and Performance, Language and Speech, Journal of the Acoustical Society of America, and American Journal of Psychology.*

D. P. Maki is a member of the American Mathematical Society, the Society for Industrial and Applied Mathematics, and the Acoustical Society of America and is a Governor of the Mathematical Association of America.

D. B. Pisoni is director of the Speech Research Laboratory at Indiana University. He serves on the editorial boards of *Computer Speech and Language and Speech Technology.* He is a recipient of the Jacob K. Javits Neuroscience Investigator Award (1987-1995).

R. F. Port is a member of the Linguistic Society of America, the Acoustical Society of America, the Association for Computational Linguistics, and the International Neural Network Society. He reviews manuscripts for the *Journal of the Acoustical Society of America, the Journal of Speech and Hearing Research, Perception and Psychophysics, and the Journal of Phonetics.*

D. E. Robinson continues to serve as a scientific advisor to CHABA and on the Science Advisory Board of the Parmly Hearing Institute, Loyola University, Chicago. He has reviewed papers for the *Journal of the Acoustical Society of America, the Psychological Bulletin, and Developmental Psychobiology.*

R. A. Suthers is on the editorial board of Experimental Biology and is a reviewer for the *Journal of Comparative Physiology, Ethology, Animal Behavior, Science, Behavioral Ecology & Sociobiology, and the Canadian Journal of Zoology.* He has been an invited lecturer at numerous national and international symposia.

L. N. Thibos serves as editorial reviewer for *Optometry and Vision Science* and *Vision Research*, and is Topical Editor for "Clinical Vision and Visual Optics", *Journal of the Optical Society of America.* He is grant reviewer for the Air Force Office of Scientific Research, the National Science Foundation and the National Health and Medical Research Council of Australia. He is a member of the national program committee for the annual meeting of the American Academy of Optometry.

J. T. Townsend recently finished his tenure as Editor of the *Journal of Mathematical Psychology*, as well as his term on the Executive Board of the Society of Mathematical Psychology. He previously served as President of the Society of Mathematical Psychology. He continues to serve as Associate Editor of *Journal of Mathematical Psychology* and is a member of many professional societies including: *Psychonomic Society, Society for Mathematical Psychology, Society for Judgment and Decision Making, International Neural Network Society, and Mathematical Association of America.* He serves as an editorial consultant and reviewer for a number of journals and granting agencies. Dr. Townsend was recently awarded a prestigious James McKeen Cattell Sabbatical Award for the academic year 1992-1993.

Bibliography

The following is a cumulative list of archival publications by Institute investigators from January, 1987 -May 31,1992.

1987

1. Berg, B.G. (1987). Internal noise in auditory detection tasks. Ph.D. dissertation, Indiana University.

2. Dorffner, G. Kwasny, S. and Port, R. (1987). Parsing phonetic segments into syllables. In E. Buchberger and J. Retti (eds.), *Proceedings of the Third Austrian Artificial Intelligence Conference.* Springer-Verlag, Bonn, 49-63.

3. Espinoza-Varas, B. and Watson, C.S. (1987). Perception of complex auditory patterns by humans. In S.H. Hulse and R.J. Dooling (eds.), *The Comparative Psychology of Complex Acoustic Perception.*

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8. Kewley-Port, D., Watson, C.S. and Elbert, M. (1988). The Indiana Speech Training Aid (ISTRA). *J. Acoust. Soc. Am., Suppl. I,* **84**, S42. Presented at the *2nd joint meeting of The Acoustical Societies of America and Japan, Honolulu, Hawaii,* November.

9. Kewley-Port, D., Watson, C.S., Elbert, M. and Cromer, P. (1988). Indiana Speech Training Aid (ISTRA). *ASHA* **30**, 207. Scientific Exhibit presented at the 1988 Annual Convention of the American Speech-Language-Hearing Association, Boston, MA, November.

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11. Smythe, E. (1988). *Temporal Computation in Connectionist Models. Department of Computer Science,* Indiana University, Technical Report No. 251. 13 pages.

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13. Suthers, R.A. and Hartley, D.J. (1988). Subglottal chambers in the horseshoe bat affect vocal efficiency. *Association for Research in Otolaryngology.* 11th Midwinter Research Meeting.

14. Thibos, L.N. and Still, D.L. (1988). Aliasing and contrast sensitivity in peripheral vision. *J. Opt. Soc. Am.* **A4**, (suppl.).

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16. Watson, C.S and Kewley-Port, D. Computer-Based Speech Training Aids. *J. Acoust. Soc. Am.*, Suppl. I, **84**, S42. Presented at the 2nd joint meeting of The Acoustical Societies of America and Japan, Honolulu, Hawaii, November, 1988.

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18. Zhang, X., Bradley, A. and Thibos, L.N. (1988) Interaction between longitudinal and lateral chromatic aberrations in the retinal image. *J. Opt. Soc. Am.* **A4**, (suppl).

19. Zhang, X., Bradley, A. and Thibos, L.N. (1988) The beneficial effect of longitudinal chromatic aberration. *Am. J. Optom. Physiol. Optics*, **65**. 47 pages.

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21. Applegate, R.A., Bradley, A., Zeffren, B. and Van Heuven W.A.J. (1989). Psychophysical evaluation of the foveal avascular zone (FAZ) sizer and foveola location. *Invest. Ophthal. Vis. Sci.*, **30** (suppl.), 410.

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23. Bingham, G.P. (1989). Exploration of the relation between resource and task dynamics. An invited paper presented at the Workshop on Ecological Methods for Studying Perceptually-guided Action, Research Group on Mind and Brain, Center for Interdisciplinary Research, University of Bielefeld, Bielefeld, West Germany, December 1st.

24. Bradley, A. (1989). Achromatizing the human eye. Invited presentation at the 1989 Annual meeting of the American Academy of Optometry. *Optom. Vis. Sci.*, **66** (suppl.), 189.

25. Bradley, A., Applegate, R., Zeffren, B. and Van Heuver, W.J.A. (1989). Psychophysical evaluation of retinal vessels. *Opt. Soc. Am. Topical Meeting on Non-invasive Methods.*

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29. Castellan, N.J., Jr. (1989). Integrating computers into the curriculum: Challenges and rewards. Invited presentation at Computing in Instruction `89," Minnesota Community Colleges. Brainerd, MN, August, 1989.

30. Craig, J. C. (1989). Capacities and limitations of tactile processing. The International Union of Physiological Societies Satellite Symposium,Information Processing in the Somatosensory System, Wenner-Gren Center, Stockholm, Sweden.

31. Craig, J.C. (1989). Tactile channels. Paper presented to the Psychonomic Society, November.

32. Evans, P.M. (1989). Cross-modal equivalence matching and the same-different reaction-time disparity. Paper presented to the Tactile Research Conference, Atlanta, GA, November.

33. Gasser, M. (1989). Robust lexical selection in parsing and generation. *Proceedings of the Eleventh Annual Meeting of the Cognitive Science Society.*

34. Gasser, M. (1989). Towards a connectionist model of the perception and production of rhythmic patterns. *Proceedings of the Second International Workshop on AI and Music,* 99-101.

35. Guth, S.L. (1989). Colorimetry and color vision. Invited seminar presented at the first meeting of Le Club Visu," Paris, France, Nov., 1989. (Le Club Visu includes the Centre Nationale d'Etudes des Telecommunications," the Society Francaise du Vide" and the "Society des Electricians, des Electroniciens et des Radioelectriciens.")

36. Guth, S.L. (1989). Color perception and visual adaptation. Invited seminar presented at the Centre Nationale des Recherches Scientifique, Paris, France, November.38.

37. Guth, S.L. (1989). Unified model for human color perception and visual adaptation. *Proc. SPIE.*

38. Guth, S.L. (1989). Model for color vision and adaptation. *Invest. Ophthal. Vis. Sci.*, **30** (suppl.), 219.

39. Hartley, D.J., Campbell, K.A. and Suthers, R.A. (1989). The acoustic behavior of the fishing bat *Noctilio leporinus* during prey capture. *Association for Research in Otolaryngology.* Abstracts of the 12th Midwinter Research Meeting, 234.

40. Jesteadt, W. and Humes, L.E. (1989). Effect of threshold on the growth of loudness at low frequencies. *J. Acoust. Soc. Am.*, **85**, S108.

41. Kewley-Port, D. (1989). Detection thresholds for isolated vowels. *J. Acoust. Soc. Am., Suppl. 1*, **85**, S51. Presented at the 117th meeting of the Acoustical Society of America, Syracuse, NY, May.

42. Kewley-Port, D. and Watson, C.S. (1989). Computer assisted speech training for the deaf. *ASHA, 31*, 55. Presented in miniseminar Speech of Persons Who are Hearing Impaired: Historical and Current Perspectives," at the 1989 Annual Convention of the American Speech-Language-Hearing Association, St. Louis, MO, November.

43. Kidd, G. R. and Watson, C. S. (1989). Detection of relative-frequency changes in tonal sequences. *J. Acoust. Soc. Am. Suppl.* 1., **86** , S121.

44. Port, R. and Anderson, S. (1989). Recognition of continuously performed melodies. *Proceedings of the 11th Annual Meeting of the Cognitive Science Society.* L. Erlbaum Assoc., Hillsdale, NJ.

45. Robinson, D. E. (1989). Analysis of classification systems. Final Report, Contract #N6053087-87-M-360D, Naval Weapons Center, China Lake, CA.

46. Still, D.L. (1989). The effect of image quality on contrast sensitivity and acuity in central and peripheral vision. Invited presentation at the 1989 Annual meeting of the American Academy of Optometry.

47. Still, D.L., Thibos, L.N. and Bradley, A. (1989) Peripheral image quality is almost as good as central image quality. *Invest. Ophthal. Vis. Sci.*, **30** (suppl.).

48. Suthers, R.A. and Hartley, R.S. (1989). Differential airflow through the right and left sides of the avian syrinx during song. *Association for Research in Otolaryngology.* Abstracts of the 12th Midwinter Research Meeting, 308.

49. Suthers, R.A. and Hartley, R. S. (1989). The relative contributions of the left and right sides of the intact syrinx to birdsong. *Soc. for Neuroscience Abstr.*, **15**, 619.

50. Thibos, L.N. (1989). The effect of ocular chromatic aberration on visual performance. Invited presentation at the 1989 Annual meeting of the American Academy of Optometry. *Optom. Vis. Sci.*, **66** (suppl.), 189.

51. Thibos, L.N., Bradley, A. and Still, D.L. (1989). Visual acuity measured with clinical maxwellian view systems: effects of beam-entry location. *Optical Society of America Technical Digest:* Topical meeting on noninvasive assessment of the visual system, **7**, 94-97.

52. Watson, C.S. and Kidd, G.R. (1989). Proportional target-tone duration as a limit on pattern discriminability: Multi-component targets. *J. Acoust. Soc. Am.*, **86** (suppl.), S23.

53. Weisenberger, J. M., Craig, J. C. and Abbott, G. D. (1989). Evaluation of a principal-components tactile speech aid. Presented at the meeting of the American Speech-Language-Hearing Association, St. Louis, MO, November.

54. Ye, M., Thibos, L.N, Bradley, A. and Zhang, X. (1989). Does retinal illuminance affect chromostereopsis? Presentation at the 1989 Annual meeting of the American Academy of Optometry.53.

55. Ye, M., Zhang, X., Bradley, A. and Thibos, L. (1989). Chromostereopsis: The interaction of transverse chromatic aberration, axial chromatic aberration and the Stiles-Crawford effect. *Invest. Ophthal. Vis. Sci.*, **30** (suppl.), 507.

56. Zhang, X., Bradley, A. and Thibos, L.N. (1989). An estimation of the contrast contamination introduced by correction of ocular chromatic aberration. *Invest. Ophthal. Vis. Sci.*, **30**, (suppl.), 219.

57. Zhang, X., Bradley, A. and Thibos, L.N. (1989). Theoretical analysis of the effect of chromatic aberration on chromatic appearance of isoluminant color gratings. Presentation at `89 Annual meeting of the American Academy of Optometry.

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58. Applegate, R.A., Elsner, A., Jalkh, A.E. and Bradley, A. (1990). Location of the point of retinal fixation within the foveal avascular zone. Presented at the Conference on Scanning Laser Ophthalmoscopy, Microscopy, and Tomography, November.

59. Applegate, R.A., Bradley, A. and Zillio, C. (1990). See 7 micron capillaries in your own eye. Presented at the Annual Meeting of the Optical Society of America, November.

60. Applegate, R.A., van Heuven, W.A.J, Bradley, A. and Zeffren, B.S. (1990). Are current laser protocols endangering the fovea? Annual meeting of the Association for Research in Vision and Ophthalmology, May.

61. Applegate, R.A., Bradley, A. and van Heuven, W.A.J. (1990). Zapping the retinal point of fixation? Presented at the annual meeting of the American Academy of Ophthalmology, November.

62. Bingham, G.P. & Gutjahr, E.C. (1990). Perceiving the size of trees: An inkling of a solution to the scaling problem in event perception. An invited paper presented at a meeting of the *Midwestern Psychological Association* in Chicago, Il, May 4th.

63. Bingham, G.P. and Muchisky, M.M. (1990). Center of mass perception. A paper presented at a meeting of the International Society for Ecological Psychology at the Beckman Institute, University of Illinois, Urbana, Il, May 22.

64. Bingham, G.P. & Gutjahr, E.C. (1990). Perceiving the size of trees: Reducing the problem of size perception to a problem of form perception. A paper presented at a meeting of the *International Society for Ecological Psychology* at the Beckman Institute, University of Illinois, Urbana, Il, May 22nd.

65. Bradley, A., Zhang, X. and Thibos, L.N. (1990). Experimental estimation of the chromatic difference of magnification of the human eye. *Invest. Ophthal. Vis.* Sci., **31** (suppl.), 493.

66. Castellan, N.J., Jr. (1990). Decision Making: Processing Probabilistic Information. Presented to American Psychological Association, Boston, August.

67. Evans, P.M. (1990). Crossmodal pattern perception. Presented to the Psychonomic Society, New Orleans, LA, November.

68. Gasser, M. (1990). Reduplication and simple recurrent networks. First Midwest Connectfest, Bloomington, IN, November.

69. Gasser, M. and Lee, C.-D. (1990). A short-term memory architecture for learning morphophonemic rules. Third Conference on Neural Information Processing Systems, Denver, November.

70. Humes, L.E. (1990). Nonauditory factors affecting noise-induced hearing loss. NIH Consensus Conference of Noise-Induced Hearing Loss, Bethesda, MD.

71. Humes, L.E. (1990). Peripheral factors underlying the speech-recognition difficulties of hearing-impaired elderly. American Academy of Audiology, New Orleans, LA.

72. Humes, L.E. (1990). Prescribing gain characteristics of linear hearing aids. Vanderbilt/VA Symposium on Hearing Aids, Nashville, TN.

73. Humes, L.E. (1990). Loudness perception by the hearing-impaired elderly. CHABA Conference on Hearing and Aging, National Academy of Sciences, Washington, DC.

74. Humes, L.E. (1990). Application of the speech transmission index (STI) and articulation index (AI) to the hearing-impaired. Acoustical Society of America, San Diego, CA.

75. Kadlec, H., & Townsend, J. T. (1990, August). Testing separabilities and independence with signal detection analyses. Paper presented at *Twenty-third Annual Meeting of Society for Mathematical Psychology*, Toronto, Montreal.

76. Kewley-Port, D. (1990). Cross-disciplinary advances in speech science. Presented at The Future of Science and Service Seminar, ASHA National Headquarters, October.

77. Kewley-Port, D. (1990). Thresholds for formant-frequency discrimination in isolated vowels. *J. Acoust. Soc. Am.*, **87** (suppl.), S159. Presented at the 119th Meeting of the Acoustical Society of America, State College, PA, May.

78. Kewley-Port, D., Watson, C.S. and Maki, D. (1990). Small Business Innovation (SBIR) Funding: A case study in bringing a computer-based speech training aid into the marketplace. *J. Acoust. Soc. Am.*, **88** (suppl.), S196. Presented at the 120th Meeting of the Acoustical Society of America, San Diego, CA, November.

79. Kidd, G. R. and Watson, C. S. (1990). Detection of relative-duration changes in tonal sequences. *J. Acoust. Soc. Am.*, **88** (suppl.), S147.

80. Mendell, L. L. and Castellan, N. J., Jr. (1990). Search strategies in sequential decision making: Information accumulation, search termination, and information presentation effect. Presented to Midwestern Psychological Assocation, Chicago, May.

81. Pickel, K. and Castellan, N. J., Jr. (1990). Juror's evaluations of relevant and irrelevant eyewitness testimony. Presented to Midwestern Psychological Association, Chicago, May.

82. Port, R. (1990). Perceiving sound patterns in time. Presented at the Center for the Study of Language and Intelligence (CSLI), Stanford University, March 22.

83. Port, R. (1990). Toward dynamic representation of sound patterns in networks. Presented at the Phonology Laboratory, Department of Linguistics, University of California, Berkeley, March.

84. Port, R. (1990). Connectionist models of auditory pattern perception. Presented to Department of Computer Science, Butler University, Indianapolis, April.

85. Port, R. (1990). Connectionist models for auditory pattern recognition. Presented at Central Institute for the Deaf, St. Louis, MO, October.

86. Port, R. (1990). Dynamic representations in connectionist models for audition. Presented to Department of Computer Science, Washington University, St. Louis, MO, October.

87. Port, R. (1990). Grounding of auditory symbols by means of dynamic auditory memory. Presented to Society for Psychology and Philosophy, University of Maryland, June.

88. Suthers, R.A. and Hartley, R.S. (1990). Effect of unilateral denervation on the acoustic output from each side of the syrinx in singing mimic thrushes. *Society for Neuroscience Abstracts* **16**(2) , 1249.

89. Thibos, L.N., Zhang, X. and Bradley, A. (1990). Effect of ocular chromatic aberration on the luminance modulation transfer function for white light in the reduced eye. *OSA Annual Meeting Technical Digest,* **15**, 148.

90. Thibos, L.N. (1990). The effect of ocular chromatic aberration on visual performance. Visual Science Symposium: Optical limits to visual performance. *Optom. Vis. Sci.*, **67** (suppl.), 167.

91. Thibos, L.N. (1990). Is the reduced schematic eye good enough?. Visual Science Symposium: Do we need a new schematic eye? *Optom. Vis. Sci.*, **67** (suppl.), 167.

92. Thibos, L.N. (1990). New methodologies for distinguishing between optical and neural losses in vision: The Second Monroe J. Hirsch Lecture on Vision Care. *Optom. Vis. Sci.*, **67** (suppl.), 83.

93. Thibos, L.N., Zhang, X., and Bradley, A. (1990). White-light modulation transfer functions of the reduced schematic eye. *Optom. Vis. Sci.*, **67** (suppl.), 56-57.

94. Thomas, R., & Townsend, J. T. (1990, August). Stochastic dependencies in parallel and serial models: Effects on systems factorial interactions. Paper presented at *Twenty-third Annual Meeting of Society for Mathematical Psychology*, Toronto, Montreal.

95. Wilkinson, M.O., Thibos, L.N. and Cannon, M.W. (1990). Contrast constancy: neural compensation for image attenuation. *Invest. Ophthal. Vis. Sci.*, **31** (suppl.), 323.

96. Ye, M., Bradley, A., Thibos, L.N. and Zhang, X. (1990). Effect of pupil apodization on apparent visual direction. *OSA Annual Meeting Technical Digest,* **15**, 91.

97. Ye, M., Bradley, A., Thibos, L.N., and Zhang, X. (1990). The role of the Stiles-Crawford effect in determining monocular visual direction. *Optom. Vis. Sci.*, **67** (suppl.), 57.

98. Zhang, X., Ye, M., Thibos, L.N., and Bradley, A. (1990). Retinal image contrast and the Stiles-Crawford Apodization. *Optom. Vis. Sci.*, **67** (suppl.), 57.

99. Zhang, X., Ye, M., Bradley, A. and Thibos, L.N. (1990). Stiles-Crawford effect improves defocused or aberrated retinal image quality. *OSA Annual Meeting Technical Digest,* **15**, 91.

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100. Anderson, R., Wilkinson, M.O., and Thibos, L.N. (1991). Psychophysical localization of the human visual streak. *Invest. Ophthal. Vis. Sci.*, **32** (suppl.), 699.

101. Bingham, G.P. & Muchisky, M.M. (1991). Size perception in events. Presented at a meeting of the *International Society for Ecological Psychology* at Trinity College, Hartford, CT, October 19th.

102. Bingham, G.P., Muchisky, M.M. & Romack, J. (1991). `Adaptation' to displacement prisms is sensorimotor skill acquisition. Presented at a meeting of the Psychonomic Society, San Francisco, CA, November 24th.

103. Bingham, G.P. & Muchisky, M.M. (1991). Center of mass perception for the visual guidance of grasping. A paper presented at the Conference on Human Error sponsored by the Institute for the Study of Human Capabilities at Indiana University, March 22nd.

104. Bingham, G.P. & Muchisky, M.M. (1991). Center of mass perception for the visual guidance of grasping: A GSD problem. Presented at the *6th International Conference on Event Perception and Action,* Amsterdam, August 29th.

105. Bingham, G.P. (1991). The identification problem in visual event perception. Presented at a Conference on Dynamic Representation in Cognition, Indiana University, Bloomington, IN, November 16th.

106. Bingham, G.P. (1991). Detection of accretion/deletion of optical texture at occluding edges produced by eye movement with head immobilized. Presented at a meeting of the Association for Research in Vision and Ophthalmology, Sarasota Springs, Florida, April 30th.

107. Bingham, G.P. (1991). Detection of accretion/deletion of optical texture at occluding edges produced by eye movement with head immobilized. Presented at the *6th International Conference on Event Perception and Action,* Amsterdam, August 30th.

108. Bingham, G.P. (1991). Why does optical pattern never look flat? (Or the demise of 'efference copy'). Presented at the Department of Psychology, Indiana University, Bloomington, IN, October 2nd.

109. Bradley A., Rahman, A., Soni, P.S. and Zhang, X., (1991) Through-focus measures of vision with 2-zone and diffractive bifocal contact lenses. *American Academy of Optometry Symposium on Simultaneous Bifocal and Multifocal Vision.*

110. Bradley, A., Thibos, L.N., Zhang, X., and Ye, M. (1991) The effects of ocular aberration on visual performance for displayed achromatic and chromatic information. In: *Digest of Technical Papers,* Society for Information Display, **22**, 304-307.

111. Bradley, A. and Applegate, R. A. (1991). Clinical value of the vascular entoptoscope. Presented at the Fergus Fest in Cambridge, England.

112. Bradley, A., and Thibos, L. N. (1991). Incorporating the eye's optics into an applied model of detection and identifiacation of objects: Presented to the *Armstrong Laboratory Advisory Group Conference* in San Antonio, TX.

113. Evans, P. M. and Craig, J.C. (1991). Identifying the direction of simulated movement on the skin. The effects of an irrelevant stimulus. Presented to the Acoustical Society of America, Baltimore, MD, May.

114. Evans, P.M. and Craig, J.C. Tactile attention and response competition. Presented to the Psychonomic Society, San Francisco, CA, November, 1991.

115. Gasser, M. (November, 1991) Phonological performance and sequential networks. Panel on Connectionism and Phonology. Second Annual Midwest Connectfest, Columbus, OH.

116. Kewley-Port, D. and Watson, C.S. (1991). Thresholds for formant-frequency discrimination of vowels in consonantal context." *J. Acoust. Soc. Am.*, **89**, 1996.

117. Mora, Juan Pablo, Robert F. Port and Catharina de Jonge (1991) Cross-language word identification using durational cues only. Paper presented at the Acoustical Society of America. *Journal of the Acoustical Society of America* **90**, (A) 2253.

118. Merrill, John W. L. and Robert Port (1991) Fractally configured neural networks. *Neural Networks* **4**, 53-60.

119. Nozawa & Townsend, J. T. (1991). Analyses of reaction times obtained in the redundant target paradigm: Evidence for parallel processing. Twenty-fourth Annual Meeting of Society for Mathematical Psychology, August, 1991, Bloomington, IN

120. Port, Robert F. and van Gelder, T. (1991). Dimensions of difference: compositional representations in AI and connectionism. *Cognitive Science Research Report,* **40,** IU Cognitive Science Program, Indiana University, Bloomington, IN.

121. Port, Robert and Timothy van Gelder (1991) Representing aspects of language. *Proceedings of the Cognitive Science Society,* **13**, (Lawrence Erlbaum, Hillsdale, NJ) pp. 487-492.

122. Thibos, L.N. and Bradley, A. (1991). The limits to performance in central and peripheral vision. In: *Digest of Technical Papers, Society for Information Display,* **22**, 301-303.

123. Thibos, L.N., Zhang, X., and Bradley, A. (1991). The chromatic eye: A new model of ocular chromatic aberration. *Technical Digest on Ophthalmic and Visual Optics,* **2**, ThB1 1-4.

124. Thibos, L.N., Bradley, A., Wilkinson, M., and Cannon, M. (1991). New evidence for human errors in the perception of spatial patterns and contrast. Conference on Human Error, sponsored by Indiana Institute for the Study of Human Capabilities (March 20-22, 1991), 15-16.

125. Thibos, L.N., Zhang, X., Bradley, A. and Ye, M. (1991). Color-contrast modulation transfer functions and the effect of ocular chromatic aberration. *Invest. Ophthal. Vis. Sci,.* **32** (suppl.), 1210.

126. Thibos, L. N., Bradley, A. (1991). Fun with interferometers. Presented at the Fergus Fest in Cambridge, England. *Opthalmic Physiological Optics.*

127. Townsend, J. T., (1991) Invited Presentation at IU Institute for the Study of Human Capabilities, Conference on Human Error: A New Theory of Ordinal Decision Making in Statistical Inference. March 22, 1991; Bloomington, IN.

128. Wilkinson, M.O., Thibos, L.N., and Bradley, A. (1991). Neural basis of scotopic acuity. *Invest. Ophthal. Vis. Sci.*, **32** (suppl.), 699.

129. Watson, C. S., Kidd, G. R., & Foyle, D. (1991). The proportion-of-the-total-duration (PTD) rule for auditory pattern discrimination. Presented at the third annual convention of the American Psychological Society. Washington, D.C., June 1991.

130. Zhang, X., Thibos, L.N., Bradley, A., and Ye, M. (1991). Modelling effects of defocus on human eyes with large pupils. *Invest. Ophthal. Vis. Sci.*, **32** (suppl.), 1211.

1992

131. Bingham, G.P., Romack, J.L. & Buss, R.A. (1992). "Adaptation" to displacement prisms is sensorimotor skill acquisition. Presented at the Conference on Human Error sponsored by the Institute for the Study of Human Capabilities at Indiana University, Bloomington, IN, March 26th.

132. Bingham, G.P. & Muchisky, M.M. (1992). Perceiving size in events. Presented at the Department of Psychology, Indiana University, Bloomington, IN, April 1st.

133. Bingham, G.P. (1992). Perceiving the size of trees via their form. Presented at the Department of Psychology, Indiana University, Bloomington, IN, April 15th.

134. Bingham, G.P. (1992). Perceiving the size of biological objects: Form as information for scale. A paper presented at a meeting of the *Association for Research in Vision and Ophthalmology,* Sarasota Springs, Florida, May 5th.

135. Bingham, G. P. (1992). Perceiving the size of trees via their form. Presented at the *14th Annual Conference of the Cognitive Science Society*, Bloomington, IN, July 30th.

136. Bingham, G.P. (1992). Form as information about scale: Perceiving the size of trees. Presented at a meeting of the *Psychonomic Society*, St. Louis, MO, November 13th.

137. Blank, D., & Gasser, M. (1992). Grounding via scanning: Cooking up roles from scratch. *Fourth Annual Conference of the Midwest Artificial Intelligence and Cognitive Science Society.*

138. Bradley, A., (1992) Hi-tech bifocal contact lenses: a marriage of holography and vanity creates a human factors nightmare. *Human Error Conference, Indiana University.*

139. Craig, J.C., & Rinker, M.A. (1992) Effect of hand position on perception of tactile stimuli. Presented to *Psychonomic Society*, November, 1992.

140. Evans, P.M., & Florl, L.K. (1992) The perception of target and nontarget stimuli presented to the forearm. Presented to *Psychonomic Society,* November, 1992.

141. Gasser, M., & Celis, N. (1992). Towards a connectionist approach to transfer in machine translation. *Fourth Annual Conference of the Midwest Artificial Intelligence and Cognitive Science Society.*

142. Gasser, M. (March, 1992). Learning syllable representations in sequential connectionist networks. *Workshop on the Cognitive Science of Natural Language Processing,* Dublin, Ireland.

143. Gasser, M. (December, 1992) Grounding structure. Workshop on Approaches to Symbol Grounding, *Neural Information Processing Systems Post-Conference Workshops,* Vail, CO.

144. Gasser, M. Why are nominal terms learned faster than dimensional adjectives? (with Linda B. Smith). *17th Annual Boston University Conference on Language Development*, Boston, October, 1992.

145. Kewley-Port, D. (1992) Effects of levels of stimulus uncertainty and consonantal context on formant frequency discrimination. *J. Acoust. Soc. Am.*, **91**, No. 4, Pt. 2, S2338, presented at the 123rd Meeting of the Acoustical Society of America, Salt Lake City, Utah, May, 1992.

146. Muchisky, M.M. & Bingham, G.P. (1992). Perceiving size in events via kinematic form. Presented at the *14th Annual Conference of the Cognitive Science Society*, Bloomington, IN, July 31st.

147. Romack, J.L., Buss, R.A. & Bingham, G.P. (1992). "Adaptation" to displacement prisms is sensorimotor learning. Presented at the *14th Annual Conference of the Cognitive Science Society*, Bloomington, IN, July 31st.

148. Watson, C. S., & Kidd, G. R. (1992). Psychoacoustics and psychophysics of auditory warnings and displays. Presented at the *Conference on Human Error*, Indiana University, Bloomington, Indiana, March 1992.

1993

149. Bingham, G.P. & Romack, J.L. (1993). Targeted reaching with perturbation of visual direction. Presented at the *18th Annual Interdisciplinary Conference*, Jackson Hole, Wyoming, January 17-22.

150. Bingham, G.P. (1993). Spatio-temporal information in visually guided reaching. Presented at the conference sponsored by the *Office of Naval Research on Neural Representations of Temporal Patterns* at Duke University, Durham, North Carolina, May 1st.

151. Gasser, M. (March, 1993). A neural network model of developmental changes in naming behavior (with Linda B. Smith). *60th Meeting of the Society for Research in Child Development,* New Orleans.

152. Guth, S.L. (1993). Unified model for human color perception and visual adaptation, II. Presented at SPIE/IST conference, San Jose, CA, February, 1993.

153. Guth, S.L. (1993). ATD model for color and adaptation. Paper to be presented at *ECVP (European Conference on Visual Perception)* Ediburgh, Scotland, August, 1993.

154. Guth, S.L. (1993). ATD model for color appearances, discriminations and adaptation. Paper to be presented at *Euro Display '93*, Strassbourg, France, September, 1993.

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